Haemodialysis Water Pre-Treatment Plant

Wireless Monitoring System

Royal Perth Hospital

"A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering."

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Executive Summary

Currently most of the remotely monitored equipment at Royal Perth Hospital is hardwired, but is gradually being replaced with wireless systems with the development of cheaper and more reliable solutions.

This thesis tests and compares two wireless systems and analyses which one best fits Royal Perth Hospital's requirements. Thorough testing and comparison was required because once installed, the selected solution was required to be the main monitoring system used in the future.

From there the selected system was installed and commissioned within the Pre-Treatment Plant of Haemodialysis. Commissioning of the chosen software entailed configuring the manufacturers Web Server with required sensor settings, alarm limits and email addresses. In addition to the installation, this thesis briefly investigates the possibility of a fully automated chlorine analyser for the Pre-Treatment Plant. This would create an excellent long term logging solution with the nurses no longer needing to hand test chlorine levels each day.

Although the Web Server satisfied the hospitals needs in the short term, a longer term solution needed to be found. Perl script was created to communicate from the Web Servers data tables to Royal Perth Hospitals' server. This script was able to transfer all required data and pass it through to the new server, Fully Automated Nagios. This new script allows for improved data viewing, emailing capabilities, and longer term data storage.

This thesis summarises the work required to install, commission and configure a system that monitors pressures, temperature and contact switches, as well as educate the reader on the development, implementation and testing of such a system.

Since the Technical Services Division has an ISO 9001 accredited QA system, as required a large part of this thesis focused on the development of the project details, such as the development of wiring diagrams, server templates, comment logs, bill of materials and most importantly, the complete service and operator manuals.

Through the research and development of this thesis it was found that the project could be used to monitor other wards and so could be repeated in the future within Royal Perth Hospital and possibly Western Australian Health.

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Terminology and Acronyms

BOM: Bill of Materials.

FAN: Fully Automated Nagios.

Haemodialysis: Process of removing waste and excess water from the blood, providing artificial replacement of lost kidney function in people with renal failure.

LAN: Local Area Network.

LINUX: Linux is an operating system, much like UNIX. Other operating systems include Windows, MAC OS and UNIX.

ODBC: Acronym for Open Database Connectivity, it is a standard database access method. ODBC can allow any data be accessed from any application.

Perl: Perl is a script based programming language, and is used for a wide range of tasks. E.g. system administration, web development, network programming etc. (11)

RO: Reverse Osmosis (RO) is a membrane-technology filtration method that allows the removal of many types of large molecules and ions from any solution by applying pressure to the solution when it is on one side of a selective membrane. (12)

RPH: Royal Perth Hospital.

RSSI: Received Signal Strength Indication, within wireless communication.

RTD: Acronym for Resistive Temperature Device, it is a sensor used to measure temperature by correlating the resistance of the RTD element with actual temperature. RTD’s are usually used when high repeatability and accuracy are an important factor. (14)

SCADA: Supervisory Control and Data Acquisition (SCADA) systems monitor and control operations by gathering data from sensors, either at a facility or remote station, send the information to a central computer system that can manage the operations using the information gathered. (13)

SNMP: Acronym for Simple Network Management Protocol not only allows the user to view information about managed system, it also allows for system configuration. SNMP configuration abilities are dependent on the vendor implementation of SNMP on the device. (15)

SSH: Secure Shell (SSH) is a command interface and protocol that allows a user to securely gain access to a remote computer.

TSD: Technical Services Division, within Medical Engineering and Physics Department of Royal Perth Hospital.

TSSU: Theatre Sterile Supply Unit, Department within Royal Perth Hospital.

Chapter 1: Introduction

Project Background

This project is a continuation of a similar project carried out at Shenton Park Hospital. The project named "Dialysis Water Pre-treatment Plant Monitoring" written by Yohanes Chong, was responsible for monitoring a couple of remote pressure sensors ("Dialysis Water Pre-Treatment Plant Monitoring", Royal Perth Hospital 2005). However the dialysis unit was closed down before the project could be completed due to excess amounts of water wasted in the process (approximately 3600L/hour wastage).

A new modern dialysis and water pre-treatment system was installed at RPH by a private company called Fresenius (www.fmc-ag.com) where the amount of water wasted in the pre-treatment process was dramatically reduced. The Aqua B Duo 100 (www.fmc-ag.com) (central double pass reverse osmosis water treatment system) only uses 538L/hour which is fed into a drain and pumped back into the Gastroenterology Storage Tank so there is no wastage. The new system is thus much more efficient to operate and has lower running and maintenance costs.

There has also been a long running project to find a suitable wireless monitoring solution for the hospitals large Laboratory department and support for smaller installations. The plan is to use this project to test the suitability of such a system.

Project Scope

The main goal is to implement a simple, cost effective remote monitoring system for the Dialysis unit. The aim of the monitoring system is to provide early detection of any problems with the system and alert the appropriate personnel. If problems arise, it could impact upon patient treatment.

This project required testing and evaluating suitable hardware and software systems to implement in the installation of Haemodialysis as well as the planning for TSSU and Gastroenterology.

The design of the Pre-Treatment Plant was to provide basic monitoring, alarm alerts, remote viewing and the ability to log data for at least ten years. The design was not to implement a full SCADA system, but start by implementing a smaller scale ZigBee (www.zigbee.org) system to be used as a stepping stone for future developments.

A large scale SCADA system will be evaluated after this project for Laboratories within Royal Perth Hospital and more global considerations for Western Australian Health to accomplish a more streamline monitoring system within Hospitals and Health Care Facilities. A SCADA system will not be included in this project though, and is a consideration for future expansion after the completion of this project.

Appendix A contains the full System Overview Diagram.

Project Objectives

This project and many of its objectives were pre-specified prior to the thesis project being undertaken.

Test and compare two ZigBee Hardware and Software Solutions

ZigBee was chosen as the wireless communication protocol because it offers low data rates, long battery life and is best suited for periodic or intermittent data or a single transmission from a sensor or input device.

This first objective was to test and compare the two wireless systems: Wireless Sensors SensiNet System (Wireless Sensors, 2011) against the Fourtec DataNet System (Fourtec Fourier Technologies, 2011). The comparison test includes:

- Ease of installation and configuration.
- RF (Radio Frequency) Range Testing.
- Power failure recovery of the gateway.
- Quality and type of nodes/sensors.
- Radio Susceptibility/Interference on the nodes/sensors.
- Radio Susceptibility/Interference with other medical devices.
- Radio Susceptibility/Interference with existing hospital infrastructure (WiFi, Paging etc.).
- Software/Graphical User Interface (GUI).
- Service and Support Documentation.
- Cost Effectiveness.

The ZigBee system that best satisfied all test requirements would be selected for the installation of the Haemodialysis Pre-Treatment Plant and other future wireless monitoring systems at RPH.

Installation and Commissioning the Pre-Treatment Plant

The second objective was to install and commission the selected ZigBee system to remotely monitor the Pre-Treatment Plant. The installation involved:

- A site survey of the Pre-Treatment Plant.
- Creating a splash proof enclosure box, IP65 rated, to contain power supplies and wireless nodes.
- Creating a backing board to mount onto the wall with all required nodes, splash proof enclosure, conduit, and gateway. The backing board will be designed and built within the Instrument Workshop in the Medical Engineering and Physics Department once specifications are determined.
- Extend the length of pressure transducer cables to reach the plumbing mounting points.
- Calibration and installation of two pressure transducers.
- Logging a work order and scheduling final installation with Facilities Management to mount the backing board, as well as pressure transducers, conduit, contact and temperature RTD wireless sensors.
- Creating a layout diagram for Facilities Management when ready for installation.
- Creating a wiring diagram ready for installation.
- Connecting the ethernet port to the Medical Imaging VLAN (Virtual Local Area Network) and provide it with a static IP address, ready for the gateway to be connected.
- Connecting RO Status and Alarm to the Facilities Management SCADA system.

Commissioning involves:

- Verifying all sensor functionalities, performance and accuracy.
- Configuring sensor names, locations, virtual ports and conversion equations (from current to pressure) within the Web Server.
- Configuring alarm limits and email alerts for different users.
- Verifying that the gateway server can be viewed remotely through the web server browser within TSD.
- Creating a Service Manual for future installations and users.
- Creating a Visio template of the system to be uploaded onto NagVis, ready for final configuration.

Automated Chlorine Analyser in Pre-Treatment Plant

The third objective was to research an automated chlorine measurement solution to replace the manual method currently used by Nurses in the Haemodialysis Ward and if suitable system was found, to install the solution.

The objectives of the automated solution are:

- Fully automated i.e. no user interaction.
- More frequent testing.
- Total Chlorine measurement.
- Analog output to integrate with the wireless system to provide remote monitoring.
- Simple and infrequent calibration.
- Low maintenance.
- Cost effective.
- Minimal water wastage.

Fully Automated Nagios (FAN) Server

The fourth objective is to complete research into Centreon, Nagios and NagVis which is the free monitoring software package that RPH already uses to monitor other systems, but on different servers. The FAN Server had to:

- Monitor all nodes within the Pre-Treatment Plant.
- Simple GUI interface that can display recorded data and alarms.
- Record current and historical data up to a period of ten years.
- Have remote login for employees within RPH.
- Must be web based.
- Email alerts to relevant people according to the configurable limits.
- Service Manual written up for future users.

TSSU and Gastroenterology Install

The TSSU and Gastroenterology Installations were the fifth and final objectives for this project. This includes:

- Ordering hardware from Wireless Sensors.
- Planning and organising installation of the mains power/data infrastructure in TSSU.
- Creating the wiring diagrams ready for installation.
- Creating a Visio template of the system to be uploaded onto NagVis, ready for configuration.

Once these are completed, TSSU and Gastroenterology will be ready for the final stage of installation.

Project Revisions

Since the submission of the Project Plan and Progress Report there have been a few changes. The TSSU and Gastroenterology installations were due to be completed between March and April 2012. However, due to some delays, the preparation for these actual installations will take place at a later date. This in turn meant that the major PathWest installation of Laboratories was not started (mentioned in the Progress Report), which will also be left for a later date. The FAN Server was originally meant to be configured through SNMP, but after many unsuccessful attempts and a long delay, it was decided to use an ODBC interface instead. This meant a new program script needed to be written and configured.

Thesis Structure

The remainder of this thesis paper is broken down into six chapters to provide detail into the works undertaken on this project. These are outlined as follows:

- **Chapter Two:** Tests, compares and decides on the most suitable Wireless ZigBee system that meets RPH's requirements, and also provides background information about the Wireless ZigBee standard.
- **Chapter Three:** Describes the details of the Haemodialysis installation and commissioning of the selected wireless ZigBee system from Chapter Two.
- **Chapter Four:** Provides details of the automated chlorine analyser researched for Haemodialysis, with reasoning into why this did not go ahead.
- **Chapter Five:** Outlines the details of creating the FAN Server, including the initial software setup, programming and commissioning.

- **Chapter Six:** Describes the preliminary steps of the future installations within TSSU and Gastroenterology of the same project.
- **Chapter Seven:** Summarises the achievements made on the RPH project and discusses the future works, staff training and reusability of the RPH project.

Chapter 2: Testing and Selecting a Wireless ZigBee System

What is a Wireless ZigBee Network?

The ZigBee standard was designed for the sole purpose of monitoring large numbers of sensors with low data rates using very little power. ZigBee technology uses the globally available, licence-free 2.4GHz frequency band. It enables wireless applications with cost effective, low-power digital radios for wireless personal area networks (PAN). ZigBee is the only standard that offers low-latency communication between devices with no network synchronization delays. (1)

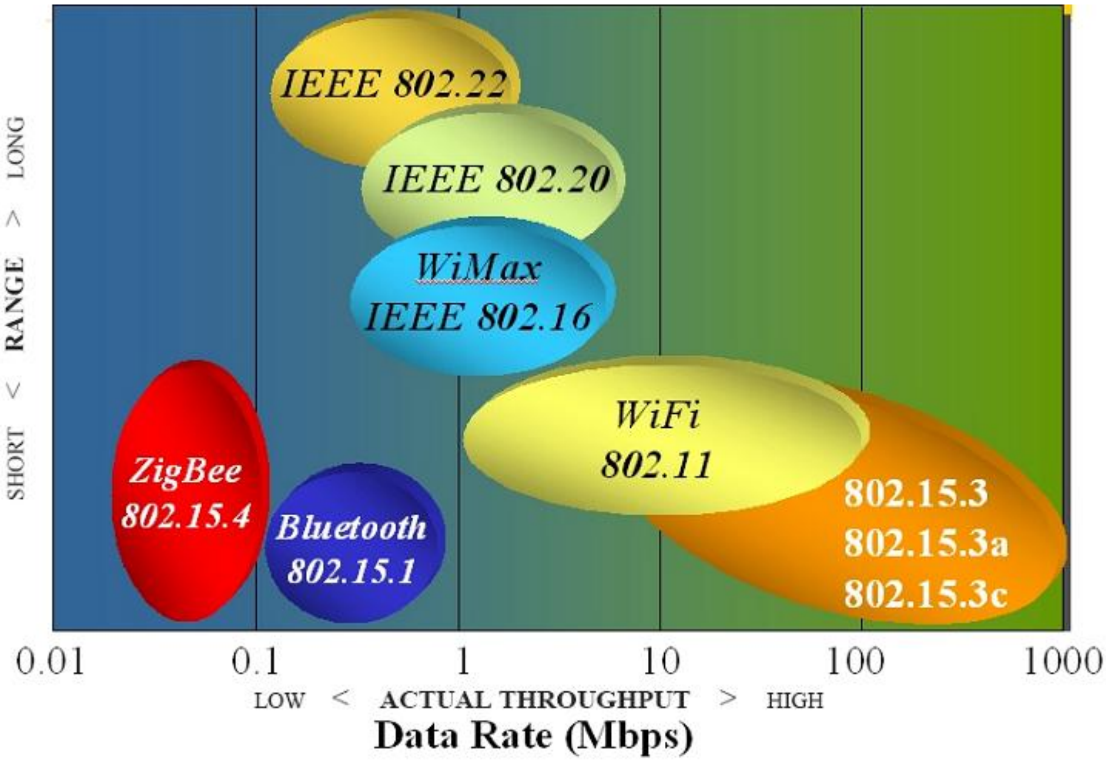


Figure 1 - ZigBee compared to other Wireless Solution (19)

"ZigBee defines the network, security and application framework for an IEEE 802.15.4-based system. These capabilities enable a network to have thousands of devices on a single wireless network. ZigBee creates robust self-forming, self-healing wireless mesh networks. The ZigBee mesh network connects sensors and controllers without being restricted by distance or range limitations." (ZigBee Alliance, 2009)

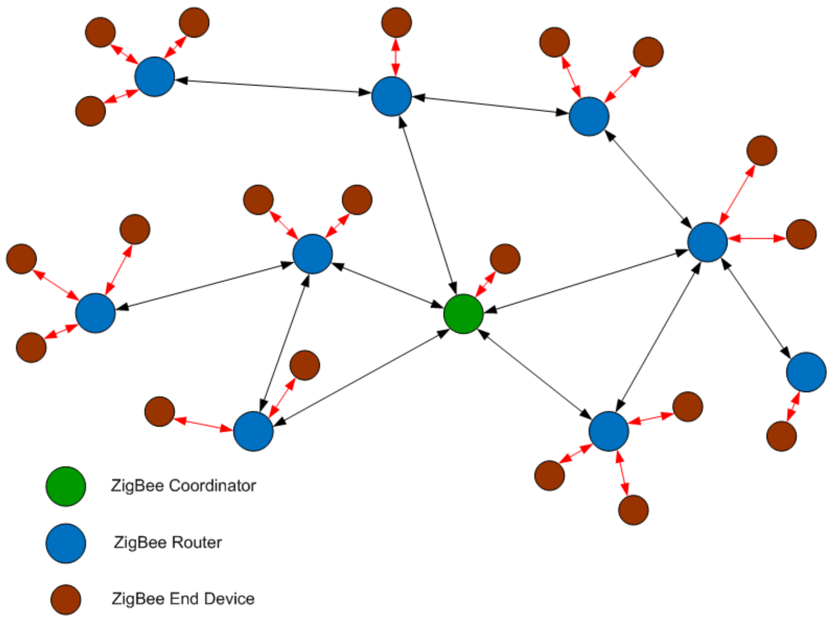


Figure 2 - ZigBee Mesh Topology

From Figure 2 above, the ZigBee Coordinator in this Project is the gateway.

The gateway is used to organise and manage the structure of the entire Mesh network. It also provides the interface between the ZigBee Wireless Network and the companies LAN.

The gateway can then either connect directly to a node (i.e. ZigBee End Device) or through a ZigBee Router (i.e. Mesh Router) which then connects to the End Device. By adding more ZigBee Routers, the user is able to extend the range of devices, or add more nodes as required.

Why a ZigBee Network was Chosen

Some of the reasons why a ZigBee network solution was chosen for this project are:

- The inherent possibility that RPH may need to shift site(s) in the foreseeable future thus making it easier to transfer the system to a new site.
- The current economic climate at RPH means the system can be installed in stages at low cost.
- The lower infrastructure costs, a wireless system provides.

Fourtec DataNet System vs. Wireless Sensors SensiNet System

Fourtec DataNet System

DataNet is an integrated hardware and software system that provides a proprietary solution based on the ZigBee standard. It is a real-time data logging solution that is driven by event-driven security policies.

DataNet delivers to its users a data logging solution that can support up to 65,000 units (theoretically), with fast, wireless installation for instant setup, see Figure 5 below. (2)

Fourtec DataNet Hardware

The DataNet range of products includes single and multichannel data loggers; see Figure 3 and Figure 4 below. They can support internal temperature and humidity sensors, as well as 4 external channels for 4-20mA, 0-580mV, 0-1V, PT-100, Thermocouple, Contact, Pulse Counter and Frequency. (2)

DataNets system has a wide selection of logger models which have a large variety of industry applications:

- DNL910 and DNL920 – ZigBee End Devices with internal temperature and/or humidity. Supports four inputs: 4-20mA, 0-1V, 0-50mV, PT-100 2 wires, Thermocouples, Contact, Pulse Counter and Frequency. Each logger can also act as a Repeater.
- DNR900 Receiver/Repeater – ZigBee Coordinator of the system which controls and collects the data from the End Devices. Also has the ability to extend the system range.
- DNR800 Mini Repeater – Act as a ZigBee Router for extending the system range.
- Mini DataNet – single and dual channel End Devices.

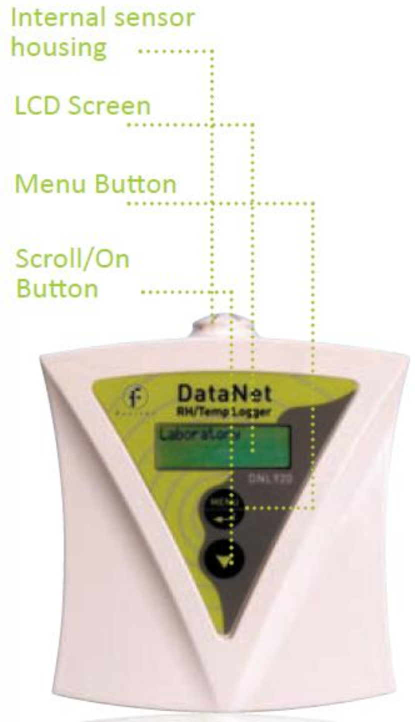


Figure 3 - DataNet Logger (2)

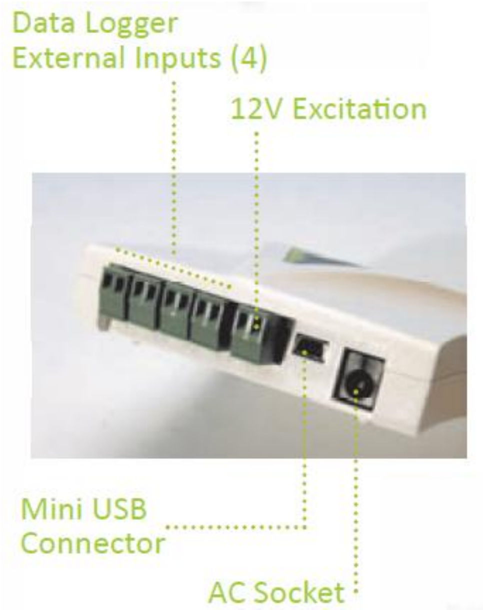


Figure 4 - DataNet Temperature Logger (2)

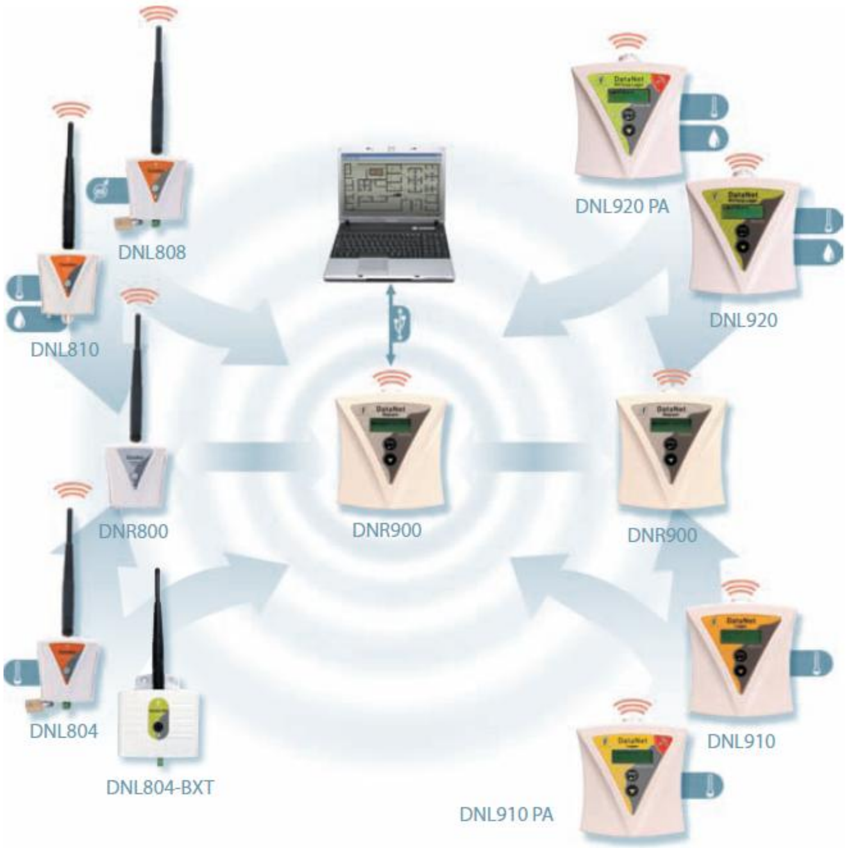


Figure 5 - DataNet Hardware System Setup (2)

Fourtec DataNet Software

The Fourtec software, DataSuite, must be installed on a local PC and is not web based. The data is stored in a proprietary file format, and thus is not Open to third party data interrogation software and cannot be stored in an ODBC compliant database.

The DataSuite Software provides security for the user's products with online monitoring and control of multiple networks supporting the entire intelligent DataNet data logging solution via LAN. The software package includes (2):

- Data View features – Presents real-time data in multiple displays (graphs, table, and statistics), see Figure 6 below.
- Sensor View – Displays real-time sensor-specific data with alarm statuses, see Figure 7 below.
- Map View – Displays to the user an international date format, ability to rename all loggers and external inputs. Also displays unit location, signal path and signal strength to the computer, see Figure 8 below.
- Alarm features – Displays alarm level setup with email and SMS notifications, four alarm levels, which allows 4 separate parameters, with alarm delays and/or durations.
- Report Module – Presents the user with an interface for creating and producing reports which could possibly have several parameters collected from the DataNet loggers and software. Reports can be emailed to a configured distribution list with selected time intervals.

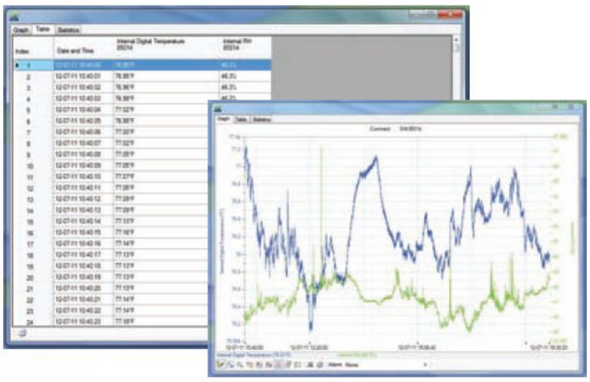


Figure 6 - Data View (2)

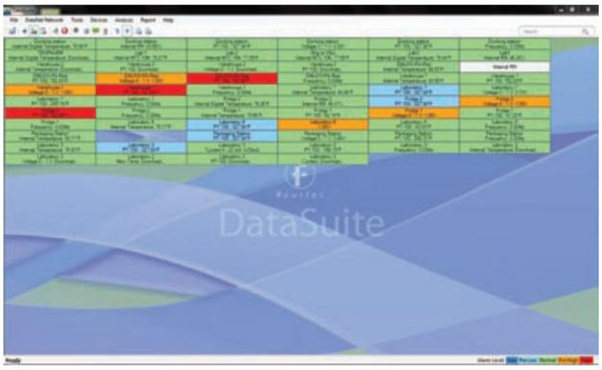


Figure 7 - Sensor View (2)

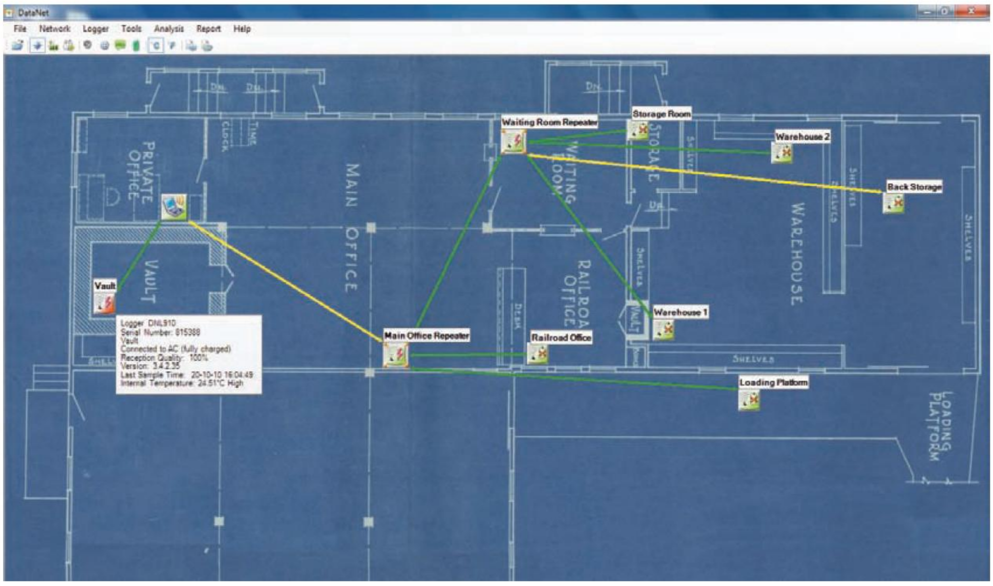


Figure 8 - Map View (2)

Wireless Sensors SensiNet System

For maximum reliability, Wireless Sensors makes use of automatic retries, acknowledgements, and a channel hopping design. Requests to join by new nodes can be authenticated via an access control list so that only recognized and genuine nodes are granted access, based on unique MAC addresses. (3)

Their sensors measure ambient temperature and humidity; accept 4-20mA, 0-10V analog, PT100, pulse, and digital inputs from End Devices or meters. Integration with fieldbus and management systems is offered through at least Ethernet, ODBC, and Web Services ensuring easy integration in new and/or legacy systems. (3)

SensiNet Hardware

Wireless Sensors broad selection of sensors includes (3):

- Gateway – ZigBee Coordinator that can provide network management, Web user interface, data logging and storage, trending, alarming and multiple interfaces (ODBC, OPC, Modbus TCP, SNMP, SOAP, CSV).
- Mesh Router – ZigBee Router that configures itself into a wireless mesh network and wirelessly extends the entire network system by receiving and re-routing messages from End Devices.
- Temperature and Humidity – Temperature and Humidity monitoring End Device that reports accurate, real-time ambient level temperature and humidity measurements with in-built sensors.
- RTD – End Device that is configurable for two RTD type temperature sensors and monitors the inputs for reliability and provides alarm indication in the event of a sensor or lead wire failure, see Figure 9 below.
- Contact Input – End Device that continuously monitors the state of its inputs and reports their status on a user selectable reporting interval and can also report any change in status immediately for real-time alarming.
- Current Input (4-20mA) – Current sensing device which accepts two 4-20mA signals, see Figure 10 below.
- Voltage Input (0-10V) – Voltage sensing device that accepts two 0-10V signals.

Figure 9 - SensiNet Temperature RTD Sensor (3)

Figure 10 - SensiNet 4-20mA Current Input Sensor (3)

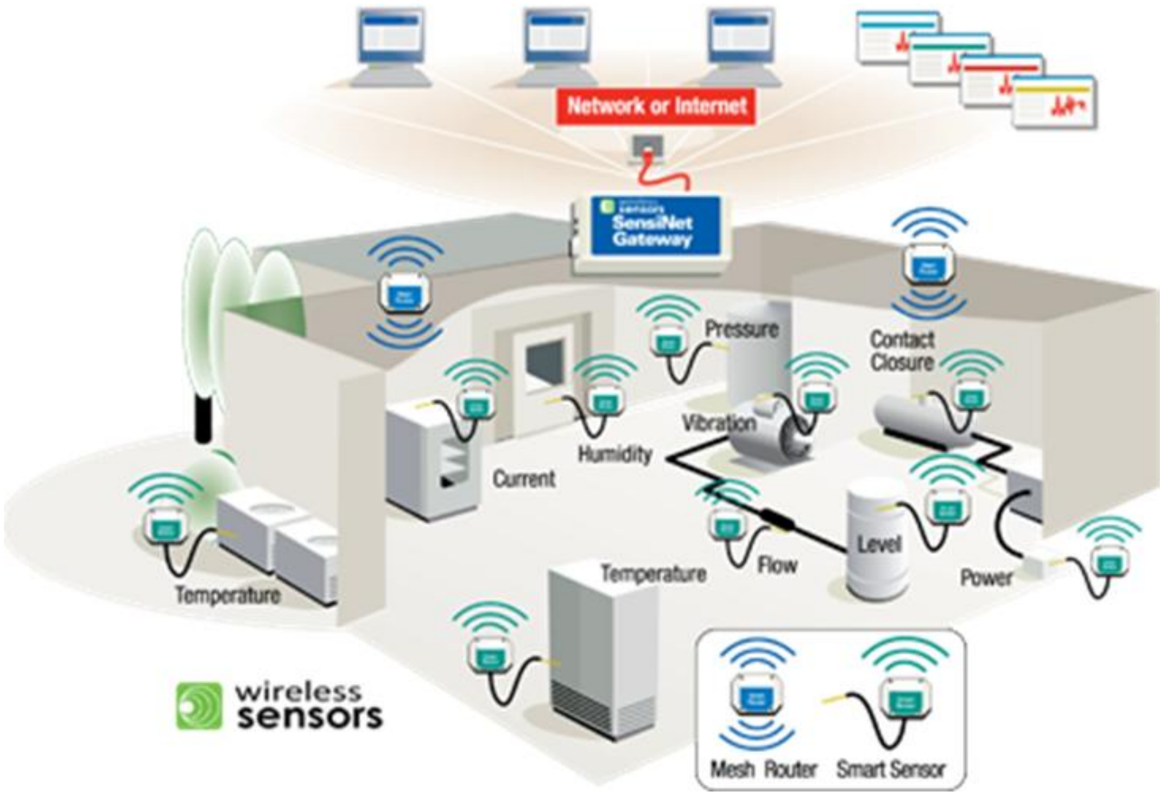


Figure 11 - SensiNet Hardware System Setup (3)

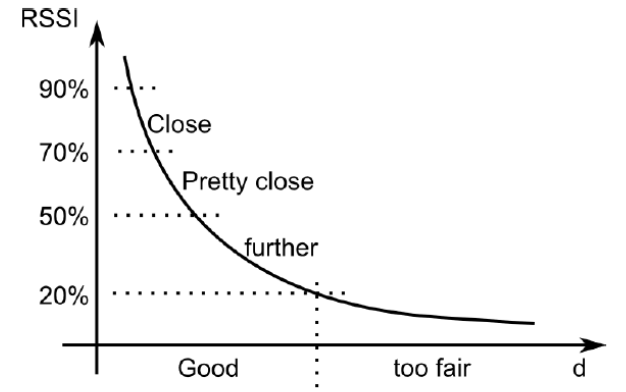
SensiNet Software

See Chapter 3 for detailed SensiNet Software information.

RSSI Interpretation

Each node sends a Report Status message every 5 minutes which contains a battery voltage and the RSSI values for both the Primary and Secondary parents of the node.

When the RSSI % value drops too low (<20%) it is difficult to determine with any certainty the other link quality. This is because very large changes in the signal strength only lead to small changes in the RSSI % value.



RSSI vs. Link Quality ('too fair' should be interpreted as 'Insufficient')

Figure 12 - Wireless Sensors RSSI Interpretation (21)

It is, therefore, not practical to install nodes where they report a <20% RSSI value. (3)

RPH Requirements and Test Results

Before a decision could be made on what system to purchase, there were requirements that had to be met and tested. These requirements were tested and the results can be seen below in the Conformance Matrix Table 1. Note that red colouring indicates failed compliance with the specifications.

	FOURTEC	**SENSINET**
INSTALLATION & CONFIGURATION		
Hardware		
Ease of connection to wireless network	Extremely difficult.	Fairly simple.
Software		
Ease of setting up	Fairly simple, but upgrade process is too involved.	Simple, but needs particular software packages already installed.
Ease of configuring devices	Easy.	Very easy.
Logging Name Character	Limited to 22 characters.	Limited to 28 characters.
Network restore	Works within approximately 3 minutes.	Works within approximately 3 minutes.
RANGE TESTING		
Between Floors – Multiple Hop	No reliable results.	Signal percentage Medium to High.
Cryo Tank – Multiple Hop	No reliable results.	Signal percentage Low to Medium.
Clean Room Level 2 – Multiple Hop	No reliable results.	Signal percentage High.
Cold Room – Multiple Hop	No reliable results.	Signal percentage High.
Open Room - Multiple Hop	Signal percentage Low to Medium.	Signal percentage High.
Through wall – Multiple Hop	Signal percentage Medium.	Signal percentage Medium to High.
Clean Room Level 2 – Single Hop	No reliable results.	Signal percentage Medium.
Cold Room – Single Hop	Signal percentage Low to Medium.	Signal percentages Low to Medium.
Open Room - Single Hop	Signal percentage High.	Signal percentage High.

Through walls – Single Hop	Signal percentage High.	Signal percentage High.
SNR (signal to noise ratio) – Reliable strength shown	No reliable results.	Very reliable.
POWER FAILURE FOR GATEWAY		
Does it recover	Yes.	Yes.
Time to recover	Within 3 seconds.	Within 4 minutes.
NODES		
Restore after replacing battery	Quick restore.	Fairly quick restore.
Any loss of configuration	No – but do need to click 'run' on each physical node.	No.
Connection to pressure transducer	Connect through 4-20mA Input.	Connect through Current Input Node.
How easy to replace batteries	Difficult, no standard batteries.	Easy, standard batteries.
General physical construction	Average.	Good.
External power needed	Receiver & Repeaters.	Mesh routers and Gateway.
Onboard Memory	~59000 samples.	No onboard memory.
Fixations	No standard fixations.	Standard across all devices.
Visual Indicators	Many. Devices and software floor map.	Only connection LEDs on Gateway and sensors.
RADIO SUSCEPTIBILITY		
Phillips CCU	Possible susceptibility problems.	Nothing noticed.
Next to working access point	Possible susceptibility problems.	Nothing noticed.

Mobile phone	Possible susceptibility problems.	Nothing noticed.
Software Monitoring	Possible susceptibility problems.	Nothing noticed.
RADIO INTERFERENCE		
Phillips CCU	Possible interference problems.	Nothing noticed.
Wireless: Access points & underneath MRI	Possible interference problems.	Nothing noticed.
Wide range of medical equipment	Possible interference problems.	Nothing noticed.
SOFTWARE		
Technology	Proprietary installation for each PC.	Web based.
Information Presented	Easy to read with Floor Map.	Easy to read, listed by device type.
View Historical Data	Yes.	Yes.
Reports	Only current data.	Both current and historical.
Network path	Poor update rate.	Network path shown always reliable.
Battery level indication / Failure	Good indication.	Good indication.
Signal Strength	Colour Identification, but not reliable.	Percentage listed, always reliable.
Ease of changing node configuration	Easy.	Easy.
Virtual labels – Ease of replacing	Easy.	Easy.
Sensor failure	Not reliable.	Updates with INVALID.
Node failure	Within 3 seconds.	Within 3 minutes.
Router failure – self healing	Yes.	Yes.

DOCUMENTATION		
User manual	Reasonably informative.	Not very informative.
Quality	Good.	Average.
Help manual	Lengthy, but helpful.	None.
Local Agent / Support / Lead – Delivery Time	Victoria AUS. Lead-Delivery Time about a week.	No local support – Agent in North America. Lead – Delivery time approx 3 weeks.

Table 1 - Fourtec & SensiNet ZigBee Solution Comparison Table

Problems Encountered

There were a few minor problems encountered in addressing the first objective, these included the ethernet cable not being sent from Wireless Sensors with the original hardware delivery, and the ethernet port within the Pre-Treatment Plant being a cross-over ethernet port. These problems were easily overcome by taking a spare ethernet cable from the TSD storeroom, and organising for Facilities Management to change the ethernet port from cross-over to standard.

Other problems faced were with the Web Server Software, there was no DNS entry and the SNMP interface had not been configured through the gateway. Since the SNMP interface was not functional, ODBC was considered and used instead. More detailed information is given in Chapter 5.

During installation, when testing was taking place, it was found that if the gateway failed in the SensiNet system, the batteries in all the nodes would rapidly deplete within a few days. This was because they would be continuously trying to connect to the gateway. This will be overcome once all email alerts are configured and the appropriate personnel are aware of any gateway failures.

Conclusion

After testing was completed and minor issues resolved, the ZigBee Hardware and Software solution selected was the Wireless Sensors SensiNet system. The main reasons for this were:

- Excellent signal strength through walls and the SNR was consistently reliable compared to the Fourtec DataNet system.
- Network information and multiple hop capabilities were much better and more reliable.
- No noticeable RF interference or susceptibility problems around network ports, mobile phones and a wide range of medical devices.
- Completely open architecture for data storage and transfer via ODBC or SNMP.
- Software was Web based – which was critical for this project.
- More cost effective (50% cheaper per channel).
- Robust, reliable and much more scalable.

The only disadvantage of Wireless Sensors SensiNet system was that there was no local support, and any problems or issues that were found during testing had to be emailed to the manufacturer in the USA. The turnaround time for each problem to be resolved was approximately 48 hours, which meant that testing took a few days longer overall than

originally expected. The quality of the User Manual was average, and not very informative, which is why any problems faced when testing their equipment had to be resolved by the manufacturer, and not by simply looking through the user or help manuals.

There were also a few limitations with the Web Server interface, but these will be fixed when later firmware revision upgrades are available.

Since most of the required hardware had already been delivered to RPH from the testing stage, this meant that the next stage, installation of the hardware, could be started immediately while waiting for the rest of the hardware to arrive.

Chapter 3: Dialysis Reverse Osmosis Monitoring System Installation

System Planning

Before this project began, additional GPO's (General Purpose electrical supply Outlets) and network ports were included in the installation of the Pre-Treatment Plant. This was because it was known that in the near future a monitoring system would be implemented.

System planning began with ordering the rest of the required hardware from Wireless Sensors in the USA, since these items had a long lead time.

Facilities Management within RPH was then contacted to obtain the required conduit and organizing a work order for installation to take place within two weeks.

The Power Supply Box Bill of Materials can be found in Appendix G.

Purchasing and Fabrication

The purpose of the power supply box was for electrical safety, keeping the 240V away from wet areas (i.e. IP65 rated) and was also convenient to provide power to the Contact Sensor and Current Input Sensor within the enclosure. The DC power supply to the Gateway was provided by a DIN-rail mounted AC-DC power supply.

The requirements of the Power Supply Box were:

- Water resistant (IP65).
- Must have a safe, reliable DC supply to the Gateway and Sensors.
- Wall mountable.
- RF Transparent so that Nodes could transmit to the Gateway.
- Enclosure had to be a commercial off the shelf item, making repeat projects easier.
- Had to contain the RO equipment alarm/status cable splitter wiring harness.

The PVC backing board was designed and built in the Instruments Workshop to hold the power supply box, Temperature/Humidity sensor, Gateway and possibly the Automated Chlorine measurement unit. This way, when installation took place, Facilities Management only needed to mount the PVC backing board to the wall, and not the entire system. (See Appendix B, Figure 38, for final PVC backing board display).

The full system assembly Bill of Materials can be seen in Appendix H.

In order for the Web Server to be setup to communicate with the Gateway, a static IP address needed to be assigned to the Gateway.

Two pressure transducers had already been purchased (for the old Pre-Treatment Plant at Shenton Park Hospital) with 4-20mA outputs. Before installation could take place, these needed to be calibrated and conversion equations calculated before they could be wired into the 4-20mA Current Input Sensors. These conversion equations would end up being used to create the virtual ports within the Wireless Sensors Web Server.

The pressure transducers were calibrated using a Druck Digital Pressure Indicator, Air Syringe, and previously setup ADAM Module Hardware (remote I/O device) (www.advantech.com/eautomation/remote-io) with LabVIEW software. See Figure 13 below.

The procedure included:

Setup the apparatus to inject air pressure through the transducer, to the ADAM module. Then compare input pressure, with the displayed current reading from the LabVIEW program. Repeat this for pressures 0, 100, 200, 300, 400, 500, 600 and 700 kPa. Repeat again for second transducer.

Create conversion equations for both Pressure Transducers from mA to kPa.

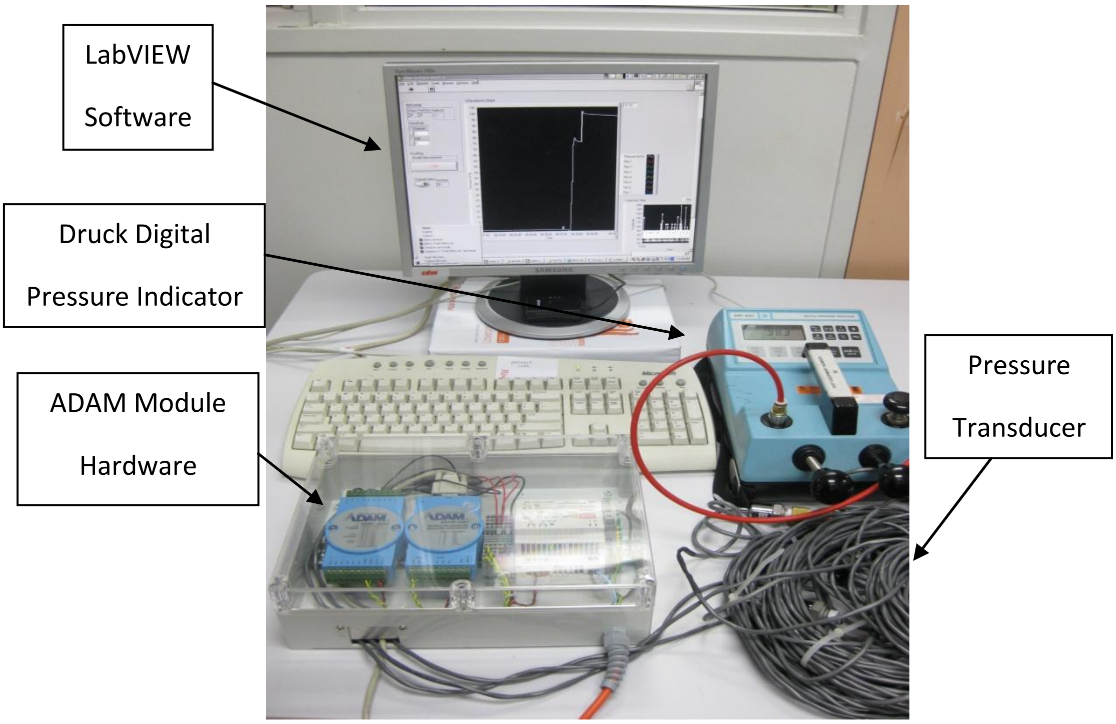


Figure 13 - RPH pressure calibration testing

The results below were for the first pressure transducer:

Serial Number: 8-091506B031	
Pressure (kPa)	**Current (mADC)**
0.8	4.1
100.8	6.49
202.2	8.87
300.7	11.16
400.85	13.51
500.95	15.81
600.85	18.1
700.95	20.36

Table 2 - Pressure Transducer 1 comparing measured Druck pressure against LabVIEW current reading

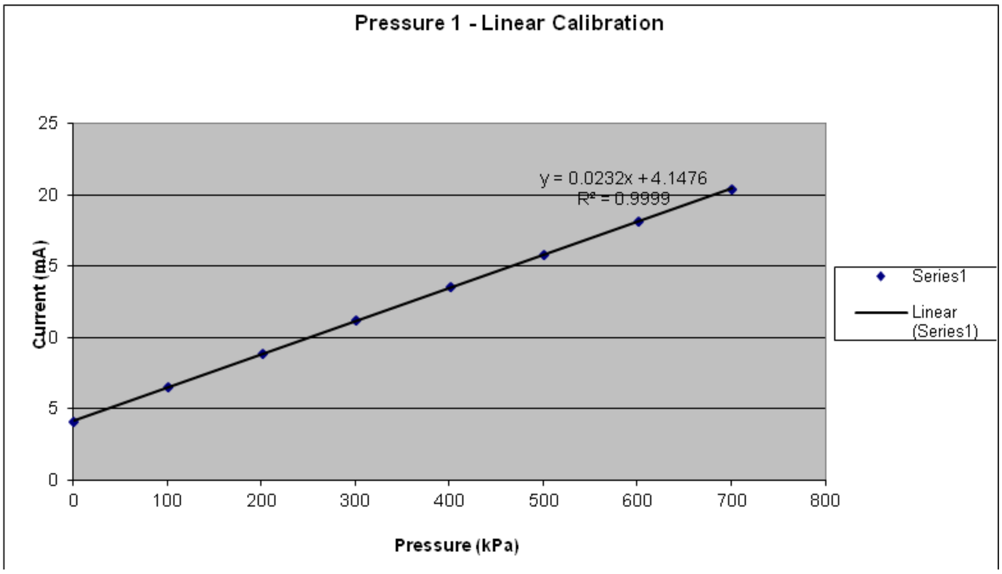


Figure 14 - Pressure Transducer 1 Linear Calibration

Verification was done by comparing the Druck pressure against the measured LabVIEW pressure and the percentage error was less than ±1.1%.

Serial Number: 8-091506B031		
Given - Druck Pressure (kPa)	**Measured Pressure (LabVIEW) (kPa)**	**Percentage error**
100.1	100.88	0.773196
200.3	202.43	1.052216
300.1	302.22	0.701476
400.7	402.73	0.50406
500.7	502.13	0.284787
600.3	599.11	-0.19863
700.9	700.28	-0.08854

Table 3 - Pressure Transducer 1 calibration verification

The test was done once again for the second transducer and conversion equation also determined. The conversion equation for pressure transducer 1 can be seen on the Pressure Transducer Linear Calibration graph, Figure 14 above.

The hardware bought from Wireless Sensors for Haemodialysis included:

- 1 x Gateway
- 1 x Gateway bracket
- 1 x 4-20mA Current Input Sensors
- 2 x Contact Switch Sensors
- 1 x Temperature RTD Sensor
- 1 x Ambient Temperature/Humidity Sensor

These sensors and parts ended up taking approximately five weeks to arrive, because the order was held up in customs, which meant quite a large delay in the project.

The total cost of the system assembly was $3905.70, the cost details can be seen in Appendix G and H, listing the Bill of Materials (BOM). A BOM needed to be created to estimate how much the future installations for TSSU and Gastroenterology would cost, which meant every item was documented.

Installation

Installation took 3 days to complete, including the final installation of the Break Water Tank Contact Closure and Gateway mounting bracket when they arrived five weeks later. The installation required a Facilities Management Team member to mount the PVC backing board,

with all fixations attached, to the wall. The conduit was then aligned against the conduit already attached to the backing board and fixed along the walls to hold the pressure transducer wiring. The pressure transducers were sterilized and fixed to the already installed attachments.

See Appendix B for the Haemodialysis Installation photographs and Appendix C for the Wiring Diagram of Haemodialysis.

Calibration Checks

Every 12 months calibration checks are needed for sensors:

SENSOR	WHEN	METHOD
RTD Temperature	Every 12 months	Check against RO Hotfeed (Note: Approximately 3˚C offset)
Current (Pressure)	Every 12 months	Check against Analog Gauges (Note: Fresenius should be calibrating pressure readings once a year also.)
Temperature/Humidity	Every 12 months	Check against Temperature sensor on other wall. Humidity to be calibrated against independent Humidity sensor.

Table 4 - Sensor Calibration Checks

Commissioning of Wireless Sensors Web Server

Commissioning of the Web Server was one of the larger parts of this project which first involved verifying all sensor functionalities, performance and accuracy. This included checking that the Web Server could connect to the Gateway through the static IP address. Once communication and sensor functionality was determined, configuring all sensor names, locations within RPH, virtual ports and conversion equations needed to be configured, which was done after obtaining the user manual and technical guides, but a Service Manual specific to RPH was also required.

The Web Server was initially a temporary monitoring solution and would be superseded by the FAN Server, explained later in Chapter 5.

Network Setup

The preferred Web browser is Mozilla Firefox (Version 6, although it is also compatible with Internet Explorer Version 7 or greater), the web address is noted and login details explained.

Configuring the Wireless Sensors Gateway

Before configuration could begin, we needed to connect the Antamedia software which was a temporary DHCP (Dynamic Host Configuration Protocol) server to allow the Gateway to obtain an IP address. This was necessary to gain access to the web portal to allow further configuration including changing the network settings to a static IP rather than a DHCP, which would allow connection to the Hospital's intranet. Inside, the network configuration details needed to be entered so communication with RPH's server could be made. A LINUX machine and SSH was used later to set the DNS (Domain Name System) server address. This was necessary to make the email work by Server Name (DNS) rather than requiring an IP address, see Figure 25. (Note: this step should not have been necessary as the manufacturer needs to allow this setting to be changed through the Web Server itself).

Network Formation

Network Formation can be seen via the Network Summary page of the Web Server, as seen in Figure 15 below:

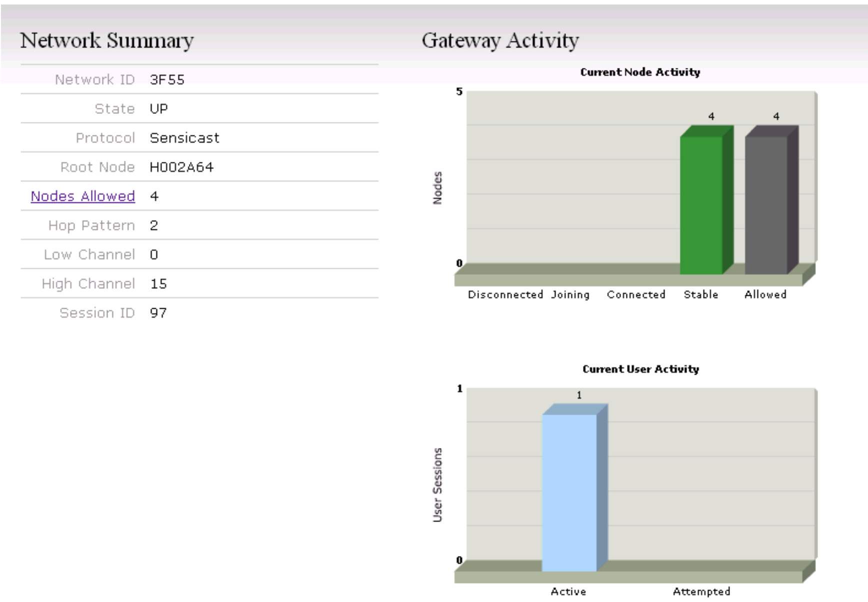


Figure 15 - Gateway Network Summary

The Gateway Activity represents:

- Disconnected: Node has been configured for that gateway, but has been turned off, is out of range, or batteries have been depleted.
- Joining: Node has been turned on, and is in the process of connecting to the Gateway for configuration into the wireless network.
- Connected: Node has previously been configured to the gateway, is now in the process of being connected and monitoring data.
- Stable: Connected node is within operational range of the gateway.
- Allowed: Node has security clearance to communicate to the gateway.

Listing Nodes

A Node Summary can be seen in Figure 16 below, where each node associated with the Pre-Treatment Plant gateway needed to be individually added and specific details configured.

Nodes

Nodes allowed in your network are listed here. To configure a node click on its Radio ID.

Node	Type	Short	State	RSSI-P	RSSI-S	Ports	Last Data Rpt	Battery
H002A6429F3D	BRDG	1	Stable	N/A	N/A	0	None received	3.32
H002ADE3D0ED	CONT	2	Stable	68%	--	2	2012-03-12 11:24:43	2.92
H002AD46CF40	CONT	3	Stable	80%	--	2	2012-03-12 11:21:47	3.02
H002B6820979	TEHU	4	Stable	82%	--	2	2012-03-12 11:22:21	3.12
H002B69641ED	CURR	6	Stable	82%	--	2	2012-03-12 11:25:53	3.2
H002B6F3FB4D	TEMP	8	Stable	52%	--	2	2012-03-12 11:24:35	3.02

Add more nodes

Figure 16 - List Node Summary

Node = Unique Network Serial Number that provides a link to allow customisation and setup of the individual node.

Type = Type of node (e.g. BRDG = Gateway, CONT = Contact Switch, TEHU = Ambient Temperature/Humidity, CURR = 4-20mA Current, TEMP = RTD Temperature).

RSSI-P = Return Signal Strength Index – Primary (This is the RF signal strength for the main RF path and for this installation is directly between the Node and the gateway).

RSSI-S = Return Signal Strength Index – Secondary (This is an alternative RF signal path, automatically chosen if the primary path fails and is typically from a Node through a Mesh Router).

Short = Order that nodes were added to the network.

Port = How many available ports there are on that sensor.

Battery = Battery level of that sensor (Must be greater than 3.00V for the Gateway, and greater then 2.90V for all other sensors).

Node Configuration

All nodes have been configured with the following:

- Heartbeat Interval (How often the Node verifies its network connection status with the Gateway) – 300 seconds (5 minutes)
- Reporting Interval (How often the Nodes transmits data to the Gateway) – 300 seconds (5 minutes)

Below are the configurations of each node:

- Current Node: A dual channel 4-20mA sensor that is used to measure the pressure signals.

Port	Associated	Parameter	Value	Status
Current-1	Yes	Polling Interval		Not changed
		Activate Port	Active	Not changed
		External Power	External power required	Not changed
Current-2	Yes	Polling Interval		Not changed
		Activate Port	Active	Not changed
		External Power	External power required	Not changed

Figure 17 - Current Node Configuration

- Ambient Temperature/Humidity: Only needed the Heartbeat and Reporting Intervals to be configured.
- Temperature Node: Measuring the incoming and outgoing temperature of the Sterilization unit.

Port	Associated	Parameter	Value	Status
Temperature-1	Yes	Polling Interval	Wakeup Required	Not changed
		Activate Port	Active	Not changed
		RTD Type	Platinum PE 100,385	Not changed
		RTD Config	3 Wire	Not changed
Temperature-2	Yes	Polling Interval	Wakeup Required	Not changed
		Activate Port	Active	Not changed
		RTD Type	Platinum PE 100,385	Not changed
		RTD Config	3 Wire	Not changed

Figure 18 - Temperature Node Configuration

- Contact Closures: Only needed the Heartbeat and Reporting Intervals to be configured.

Node Locations

- Locations needed to be configured for each node, stating their Location Name and Associated Type (i.e. Battery Voltage, Node Status etc,):

Add New Location

Tag ID (#) | Location Name | Add New

Existing Locations

Delete	Tag ID	Location Name	Mapping	
X	1	Dialysis - Contact - Break Tank - Battery	Remove	H002ADE3D0ED Battery Voltage
X	1	Dialysis - Contact - Break Tank - Status	Remove	H002ADE3D0ED Node State
X	1	Dialysis - Contact - Break Tank OK	Remove	H002ADE3D0ED Contact Closure-1
X	1	Dialysis - Contact - RO - Battery	Remove	H002AD46CF40 Battery Voltage
X	1	Dialysis - Contact - RO - Status	Remove	H002AD46CF40 Node State
X	1	Dialysis - Contact - RO Alarm Fault	Remove	H002AD46CF40 Contact Closure-2
X	1	Dialysis - Contact - RO Alarm OK	Remove	H002AD46CF40 Contact Closure-1
X	1	Dialysis - Current - Battery	Remove	H002B69641ED Battery Voltage
X	1	Dialysis - Current - Status	Remove	H002B69641ED Node State
X	1	Dialysis - Current 1	Remove	H002B69641ED Current-1
X	1	Dialysis - Current 2	Remove	H002B69641ED Current-2
X	1	Dialysis - Pressure 1	Remove	H002B69641ED Pressure 1
X	1	Dialysis - Pressure 2	Remove	H002B69641ED Pressure 2
X	1	Dialysis - Room Hum	Remove	H002B6820979 Humidity-1
X	1	Dialysis - Room Temp	Remove	H002B6820979 Temperature-1
X	1	Dialysis - Temp - Battery	Remove	H002B6F3FB4D Battery Voltage
X	1	Dialysis - Temp - Loop in	Remove	H002B6F3FB4D Temperature-1
X	1	Dialysis - Temp - Loop out	Remove	H002B6F3FB4D Temperature-2
X	1	Dialysis - Temp - Status	Remove	H002B6F3FB4D Node State
X	1	Dialysis - Temp/Hum - Battery	Remove	H002B6820979 Battery Voltage
X	1	Dialysis - Temp/Hum - Status	Remove	H002B6820979 Node State

Figure 19 - Node Locations

Virtual Ports

Two virtual ports were created to convert current (mA) to pressure (kPa) for both pressure transducers. The equations were taken from the pressure transducer linear calibration graphs, earlier in Chapter 3.

	Virtual Port Name	Source Node	Source Sensor	Port ID	Equation Name
☐	Pressure 1	H002B69641ED	Current-1	33832	P_convert1
☐	Pressure 2	H002B69641ED	Current-2	33833	P_convert2

Figure 20 - Virtual Ports converting Current to Pressure

Reports

When current data is viewed, the following image is shown:

Recent Sensor Data

Location	Tag	Node	Port	Reading	Timestamp
Dialysis - Contact - Break Tank OK	1	H002ADE3D0ED	Contact Closure-1	1	2012-03-12 11:29:41
Dialysis - Contact - RO Alarm Fault	1	H002AD46CF40	Contact Closure-2	0	2012-03-12 11:26:47
Dialysis - Contact - RO Alarm OK	1	H002AD46CF40	Contact Closure-1	1	2012-03-12 11:26:46
Dialysis - Current 1	1	H002B69641ED	Current-1	14.569 mA	2012-03-12 11:25:50
Dialysis - Current 2	1	H002B69641ED	Current-2	14.002 mA	2012-03-12 11:25:52
Dialysis - Pressure 1	1	H002B69641ED	Pressure 1	452.15 kPa	2012-03-12 11:25:50
Dialysis - Pressure 2	1	H002B69641ED	Pressure 2	423.33 kPa	2012-03-12 11:25:53
Dialysis - Room Hum	1	H002B6820979	Humidity-1	33.49 %	2012-03-12 11:27:21
Dialysis - Room Temp	1	H002B6820979	Temperature-1	27.43 C	2012-03-12 11:27:20
Dialysis - Temp - Loop in	1	H002B6F3FB4D	Temperature-1	32 C	2012-03-12 11:29:34
Dialysis - Temp - Loop out	1	H002B6F3FB4D	Temperature-2	32.3 C	2012-03-12 11:29:35
		H002ADE3D0ED	Contact Closure-2	0	2012-03-12 11:29:42

Figure 21 - Current Data View

Historical Data View allows the user to view user defined nodes, and time and date.

Historical Sensor Data

Select the sensors you want to use as sources.

Select	Location	Tag	Node Address	Sensor Port
☐	Dialysis - Current 1	1	H002B69641ED	Current-1
☐	Dialysis - Current 2	1	H002B69641ED	Current-2
☐	Dialysis - Pressure 1	1	H002B69641ED	Pressure 1
☐	Dialysis - Pressure 2	1	H002B69641ED	Pressure 2
☑	Dialysis - Room Hum	1	H002B6820979	Humidity-1
☑	Dialysis - Room Temp	1	H002B6820979	Temperature-1
☐	Dialysis - Temp - Loop in	1	H002B6F3FB4D	Temperature-1
☐	Dialysis - Temp - Loop out	1	H002B6F3FB4D	Temperature-2

Continue

Figure 22 - Historical Data: Choosing Nodes

Historical Sensor Data

Select the range of dates and times for which you want to see data.

(When selecting a custom range, use the following formats: Date: "xx/xx/xxxx", Time: "xx:xx")

Use Preset Range: Custom

Start Date	Start Time	End Date	End Time
12/21/2011	12:50	12/22/2011	12:55

Save to File | Show as Graph

Figure 23 - Historical Data: Selecting Time and Date Intervals

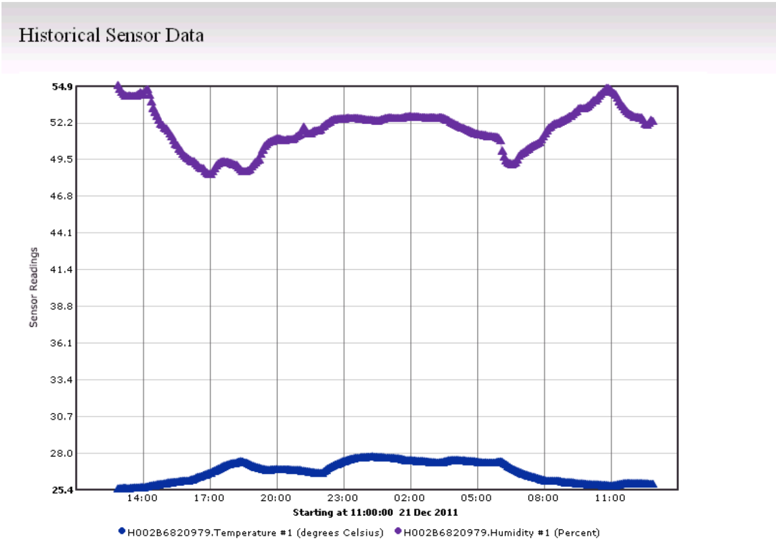


Figure 24 - Historical Data Graph

Alerts

Email alerts were setup in the short term, but eventually disabled after the FAN server was configured. They were setup using the Mailer Configuration screen:

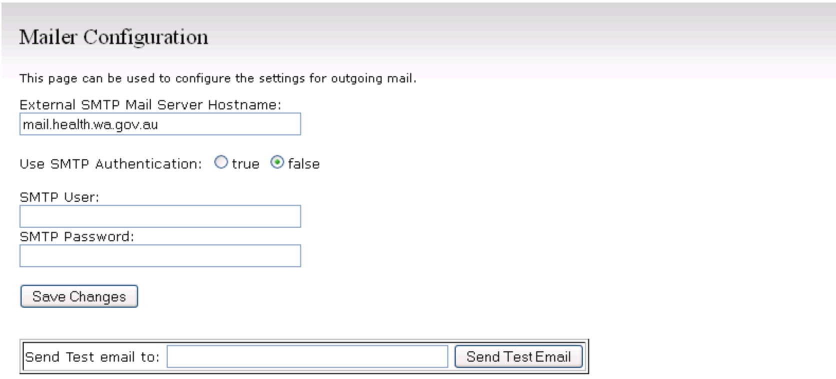


Figure 25 - Email Server Configuration

Emails were configured to be sent to the Principle Clinical Engineer, Senior Design Engineer (Electronics), TSD On-call employee and Haemodialysis Technical Officer in charge.

Alerts can be managed By Node, By Node Type and Network Event. For the purposes of this Project, they were managed By Node.

An example of creating a Temperature Node Alert is shown below:

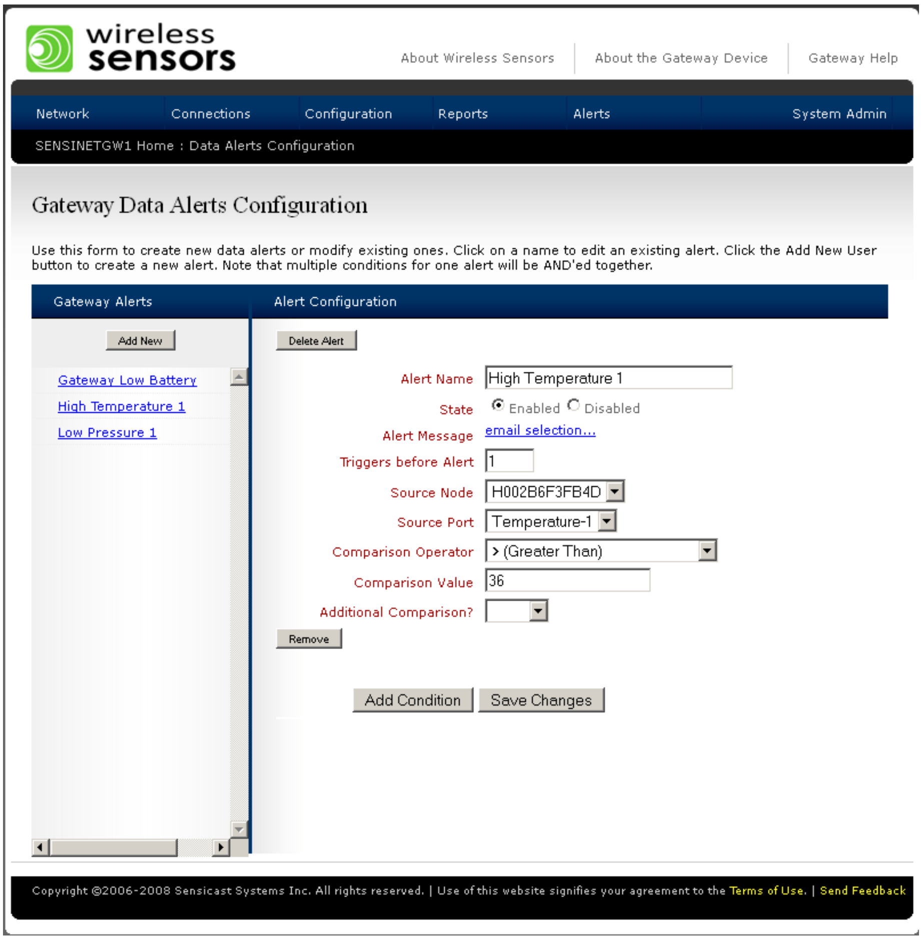


Figure 26 - Node Alert Configuration

Message Templates also needed to be created; they were configured to email the Condition of the alarm and the Alert Name i.e. High Temperature 1.

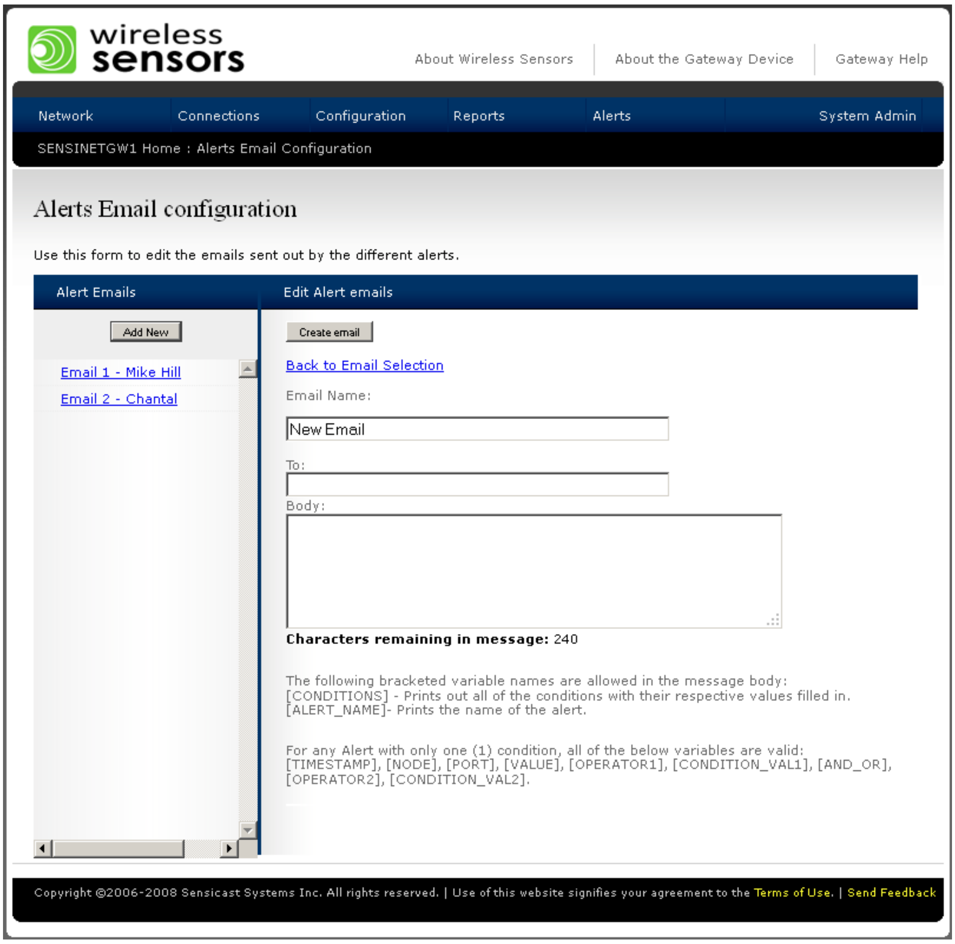


Figure 27 - Message Templates

RPH Documentation

A comprehensive documentation package needed to be completed and stored within the RPH Documentation Database for maintenance purposes and as guides to the future installations in both TSSU and Gastroenterology. It includes:

- Service Manual
- Operator Manual
- Project Summary
- Essential Principles Checklist
- Project Risk Analysis
- Project Feasibility Form
- Project Specifications
- Project Review Meetings
- Comment Log
- Bill of Materials

Problems Encountered

There were a few problems that arose during the installation and commissioning of the Wireless Sensors system. Initially when the hardware was ordered it was decided that the Pre-Treatment Plant would only need one Contact Closure sensor to monitor the status of the RO units. However, a few weeks later, after the installation was nearly complete, the Principle Clinical Engineer of TSD asked to have another Contact closure for the Break Water Tank to monitor the internal Level Sensor Switch. This was used to detect if the Break Water Tank level went too low which would cause problems for the booster pumps.

The gateway that arrived in the original delivery did not come with its own mounting bracket, so as well as ordering a second Contact Closure sensor; a gateway bracket was also ordered. This second delivery took approximately five weeks to arrive, mainly due to the manufacturer taking a lot longer than expected to send the delivery. This problem also arose in the original delivery because of a hold up in customs due to the order being over $1000.

Contacting the manufacturer in America had a turnaround time of 48 hours, which meant that when we came across any issues, there was no quick solution. Because the user manual only described steps in general terms, and there was no help manual, it became quite difficult to resolve all the issues independently. Although most issues could be solved by experimenting with the Web Server, there were still a few problems that needed greater explanation.

It was decided that the most effective way to temporarily mount the gateway was with industrial grade Velcro. The gateway with Velcro backing was attached onto the PVC backing board in the Pre-Treatment Plant. About a week later the web server was checked remotely to attempt and display the weekend's data, but no connection to the web server could be made. After a visit to the Pre-Treatment Plant it was found that the industrial Velcro glued to the back of the gateway had become detached from the PVC backing board, and was hanging by its ethernet cable. When the gateway fell, it hit and damaged one of the water valves directly beneath it and hence had a constant slow dripping of water from the valve and into the input comms side of the gateway. Luckily the power connector was disconnected when the unit fell and so the gateway was not powered and hence might be recoverable. So in an effort to save the gateway all connections were detached and sensors turned off so they would not continuously poll the gateway and lose battery life. Most of the water in the gateway enclosure was removed by spraying it with compressed air. It was then put inside a dehydrating oven at 35°C for approximately four hours. After four hours the gateway was tested and still functioned correctly. The gateway was taken back to the Pre-Treatment Plant

and temporarily attached via cable ties to existing pipes until the proper gateway bracket arrived.

Another problem was encountered when there was a system failure in the Pre-Treatment Plant as a result of the Break Water Tank emptying (the wireless contact switch that was purchased to monitor this had not arrived yet). This event had never happened previously, and caused the active booster pumps to run dry and in turn overheat. The booster pump should have switched off automatically after running dry to prevent overheating but this never happened. Because the booster pump had overheated it could not reset once the Break Tank was full of water and running correctly. After the booster pumps overheated, the two monitored pressures fell to 0kPa and the entire Reverse Osmosis System shut down for approximately six hours. The web server was able to record these events and the technical staff were able to pin point the exact time when the Break Tank ran dry to look into why this event occurred, and how long it took for the pressures to drop.

After this incident had occurred, a method to monitor the pumps and have automatic switch over when one failed was investigated. This was handed over to the Haemodialysis Ward Technical Officer for further investigation.

Another issue was that the RTD Temperature probe had an approximately 3°C offset compared to the Temperature reading through the Sterilization Unit sensor. This could be due to possible induced current from the coiled sensor wires, that there is approximately 2-3m distance from the RTD Temperature sensor and Sterilization unit, or the lack of direct contact between the sensor and water. This issue was also been passed onto the Electronic Design Team.

Chapter 4: Chlorine Analyser

Background Information

The nurses currently use a hand held chlorine analyser, by emptying 1L of water after the first Carbon Filter Tank into a bucket, take a sample and then test the total chlorine level. This level must be less than 1.0 mg/L, if the level is higher than this, they must perform a second test after the second Carbon Filter Tank. The level after the second Carbon Filter Tank is usually within the limit between 0-1.0 mg/L, but if it is does go over this limit, then Facilities Management must be contacted.

An automated chlorine analyser would be more accurate than the hand held device and obviously reduces any human error. The tests can be carried out more frequently (every 15 minutes if required), log and store results into the RPH Database and automatic alerts and emails sent out if the chlorine levels go outside the 0-1.0mg/L limit. For this objective to be satisfied, a fully-automated Chlorine Analyser must be found that is cost effective in the long run and has the confidence of the Haemodialysis nursing staff.

Chlorine in water can exist in two forms, free or combined. Free chlorine is the chemical responsible for killing bacteria and oxidizing contaminants. When chlorine is added to water, it is called free chlorine. When free chlorine and contaminants combine, they become combined chlorine. In water, combined chlorine has very little sanitizing ability, and no oxidizing ability. Total chlorine is the summation of both combined chlorine and free chlorine, and now has both oxidizing and sanitizing abilities. (4)

Requirements

Within the Pre-Treatment Plant at Royal Perth Hospital, the nurses perform a Total Chlorine test once a day for sanitization purposes. Once the SensiNet monitoring system was setup and running, everything was fully automated except the Chlorine measurement taken once a day. Research began into sourcing an automated Total Chlorine Analyser so that the nurses would no longer need to measure the Chlorine levels each day, and so they would be more accurate and regular measurements that would be logged to the SensiNet system, via a current or voltage node sensor.

Requirements for the purchase of an automated Chlorine Analyser consisted of:

- Power Requirement of 100-240VAC.
- At least one analog output of 4-20mA or 0-10V.

- IP65 rated.
- Weigh less than 3kg.
- Dimensions less than 200 x 200 x 150 mm (to fit in space allocated on PVC backing board).
- Warranty of least 12 months.
- Local agent for commissioning and support if required.
- Fully automated, no user interaction.
- Total Chlorine Measurement.
- Simple and infrequent calibration.
- Minimal water wastage.
- Cost effective.

A cost analysis matrix of the upfront cost and ongoing consumables was also required for RPH to determine whether the advantages of an automated chlorine analyser would outweigh the low cost of the hand held chlorine analyser already in use. The solution found to satisfy RPH's requirements was the CRONOS Automated Chlorine Analyser by Process Instruments.

CRONOS Automated Chlorine Analyser

The CRONOS controller is a low cost transmitter. The CRONOS basic model was chosen to keep costs to a minimum while optional comms packages allow Profibus, Modbus ASCII, Modbus RTU, Modbus TCP, HART and others, but were not required for this application (5)

CRONOS has the capability to control up to three sensors that have appropriate analog outputs and relays.

A cost analysis between the CRONOS Chlorine Analyser and hand held PalinTest was conducted, the results are shown below in Table 5:

Cost Analysis

	Manual PalinTest Chlorometer Duo PTS 027	**Automated CRONOS Chlorine Analyser**
Unit cost (Upfront)	$435	$5013 (Analyser + One electrode + SensiNet Current Closure)
Consumable costs per year	Reagents: $83.22 Glass tube: $200 Labour: $900 **Total: $1183.22**	Membrane: $245 Electrolyte: $410 Chlorine Electrode: $497.60 **Total: $1152.60**
Accuracy	? (Manufacturer could not say when asked)	Resolution: 0.01mg/L Reproducibility: ±5% Stability: -2% per month
Measurements taken per day	One	Continuous, but can also be set to specific amount (e.g. 10 mins)
Prep/measurement time	5 minutes	0
Maintenance time	10 minutes every 3-4 months	15 minutes every 3-4 months
Water wastage	1L per day	500L per day (can possibly be recycled back to the Break Tank)
Pros	Nurse staff happy No water wastage	Monitored 24/7 No labour costs Automated Remote monitoring
Cons	Possible user errors No monitoring over weekends	Nurse staff not happy Expensive capital cost A lot of water wastage Sensor does not work below 0.05mg/L

Table 5 - Chlorine Analyser Cost Analysis and Comparison Table

Conclusion

If the CRONOS Automated Chlorine test failed after the first Carbon filter, then a second test after the second Carbon filter would have been required. This meant having to purchase an additional Chlorine Probe from CRONOS which would have increased the price further, plus the additional maintenance and consumable costs.

After comparing the two chlorine analyser solutions, RPH decided to stay with the hand held PalinTest solution. The two main reasons behind this were the large upfront capital cost of the CRONOS solution, because two probes were required to provide a fully automated solution (the main requirement of this solution). When the nursing staffs were asked, which they would prefer, they were strongly against the CRONOS chlorine analyser, and preferred to stay with the hand held device. They were against this idea because 5 years prior, they had a bad experience with a new system implemented, but technology in the CRONOS system had improved greatly and their fears maybe unjustified. Between the nurses having no confidence in the new system, and the high capital costs, RPH decided to stay with the hand held chlorine analyser, until a cheaper commercial option becomes available.

Chapter 5: Fully Automated Nagios (FAN) Server

Background Information

The project now moved into installing the monitoring software, Fully Automated Nagios (FAN), which is the integration of the three software packages, Nagios (Nagios, 2012), Centreon (Ohloh Centreon, 2011) and NagVis (Ohloh NagVis, 2011). Before this could be done, some research was conducted into all three software packages. RPH requires data to be stored for 10 years.

Nagios

Nagios is a monitoring system that allows organizations to recognize and resolve IT infrastructure problems before they affect crucial processes. Nagios has the ability to monitor the users' entire IT infrastructure to guarantee systems, applications, services, and processes are functioning correctly. If a failure occurs, Nagios can notify technical staff of problems, allowing them to begin remediation processes before outages influence any processes or end-users. (6)

Nagios is an open source computer system, network and infrastructure monitoring software application. It has the ability to watch hosts and services, alerting users when error occurs and again when they are resolved. (7)

Centreon

Centreon is a network, supervision and monitoring tool and is based upon Nagios. It offers a web-based frontend to Nagios, and allows the user to be more efficient in their network monitoring. Centreon also allows the user to make their supervision information understandable by a larger range of other users. (8)

NagVis

NagVis is a visualization add-on for Nagios. NagVis can be used to visualize Nagios data and Centreons monitoring tool, e.g. display processes like a network infrastructure, see Figure 28 for an example NagVis template. (9)

Designing Human Machine Interface (HMI)

The Human Machine Interface (HMI) provides a graphical view of the Pre-Treatment Plant installation, and needs to be a simplified representation of the actual installation so that it is easy to understand and navigate.

The HMI was designed through Microsoft Visio, then converted to a Portable Network Graphic (PNG) file, with images to represent all monitored equipment, and other pieces of equipment that may play a vital role in that department/room. Once a Visio drawing was completed, and converted, it needed to be uploaded through NagVis by editing the Viewer Map.

The following image is the Haemodialysis NagVis HMI:

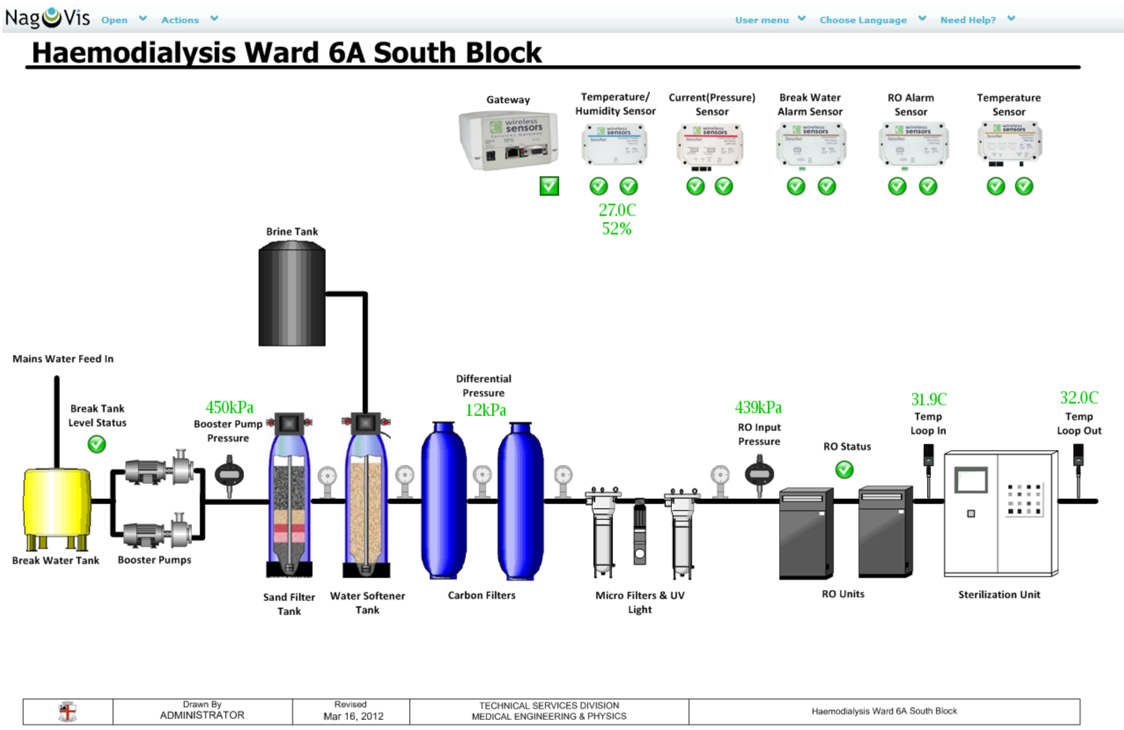


Figure 28 - Haemodialysis Ward NagVis HMI

Here, shown on the HMI, Services are represented as small circles with a tick/cross, and hosts (i.e. the gateway), are small squares with a tick/cross. If hosts and services are OK, they are coloured green, if in WARNING stage, they are coloured yellow or red if CRITICAL. The ticks represent service/host is UP and monitoring, if there is any problem, they appear with a cross inside. The pressure, temperature and humidity sensor values, together with their appropriate units, provide live readings updated every 5 minutes. The user can hover over any live reading or service and quickly view a summary of all vital values, see Figure 29 below.

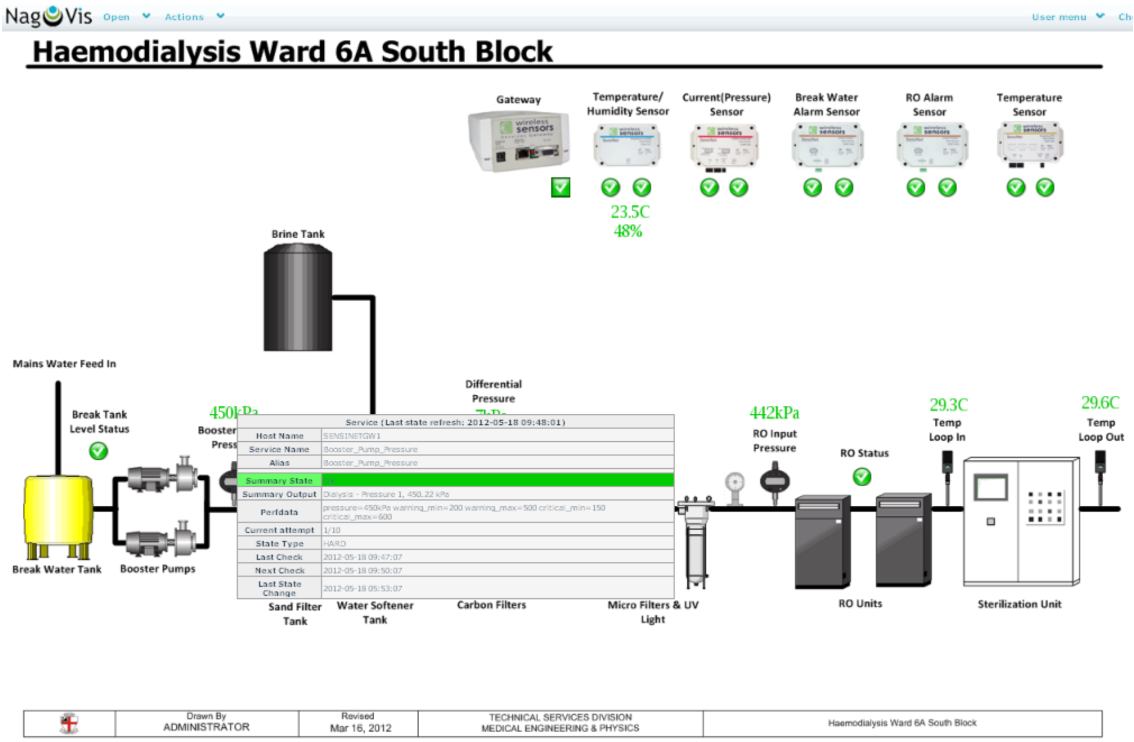


Figure 29 - Hovering over service in NagVis

Nagios & Centreon Software Setup

Before Nagios, Centreon or NagVis could be used a computer was allocated to install Fully Automated Nagios (FAN) Version 2.2. This version of FAN included Nagios 3.3.1, Centreon 2.2.2 and NagVis 1.5.9. The computer Operating System was LINUX. A Domain Name System (DNS) was configured, and then finally a default login and password.

Centreon Plug-in Perl Code

Originally, SNMP was going to be used to pull data from the gateway and pass it through to Centreon. This would have been a much simpler option as there are already plug-ins available for SNMP and Centreon, but unfortunately the SNMP service was never configured on the gateway sent to RPH. Instead, it was decided that an ODBC service would be a suitable alternative, even though there are a few less example plug-in options, there are enough for what this Project needed.

A plug-in Perl code module needed to be created from the ground up to pull data from the gateway data tables and passed through to Centreon. The Perl script creates variables, connects to the gateway database and prepares an SQL (Structured Query Language) query. From here, the script creates a data array for the results from the query and executes the query by passing the location name to the previously prepared SQL statement. The script then fetches the results of the query into the data array and prints the results onto the screen. Limits were set by checking if the printed screen results were greater or less than the warning

or critical limits. Finally, the script formats the unit output for each value type (i.e. Volts, kPa, °C) then finishes by disconnecting from the gateway database and exits with the return code for Centreon to act on.

The following flow chart,Figure 30, gives a general overview of what the Perl Script does:

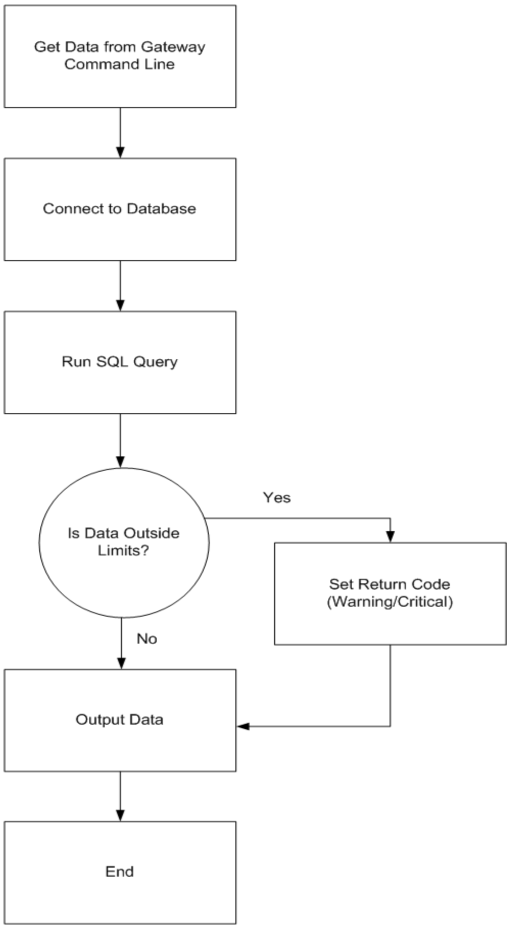


Figure 30 - Centreon Plug-in Perl Code Flowchart

See Appendix E for the complete Centreon Plug-in Perl Code.

Testing ODBC Interface on Gateway Server

The script has been designed to show OK, Warning or Critical on each service or host and was tested on the Gateway Server through Centreon where the warnings were also colour coordinated to show Green tick for OK, Yellow lightning bolt for Warning, and flashing Red cross for Critical.

Testing and Commissioning

Testing and commissioning was done by inducing alarms on NagVis and testing email alerts to each personnel. Each sensor required specific alarm limits configured, determining these values required looking back at previous data logged from the Wireless Sensors Web Server.

Viewing Data

To view sensor data, the user must click on a numerical indicator and a Centreon web page will appear with its associated information. See the figure below for an example Centreon browser window:

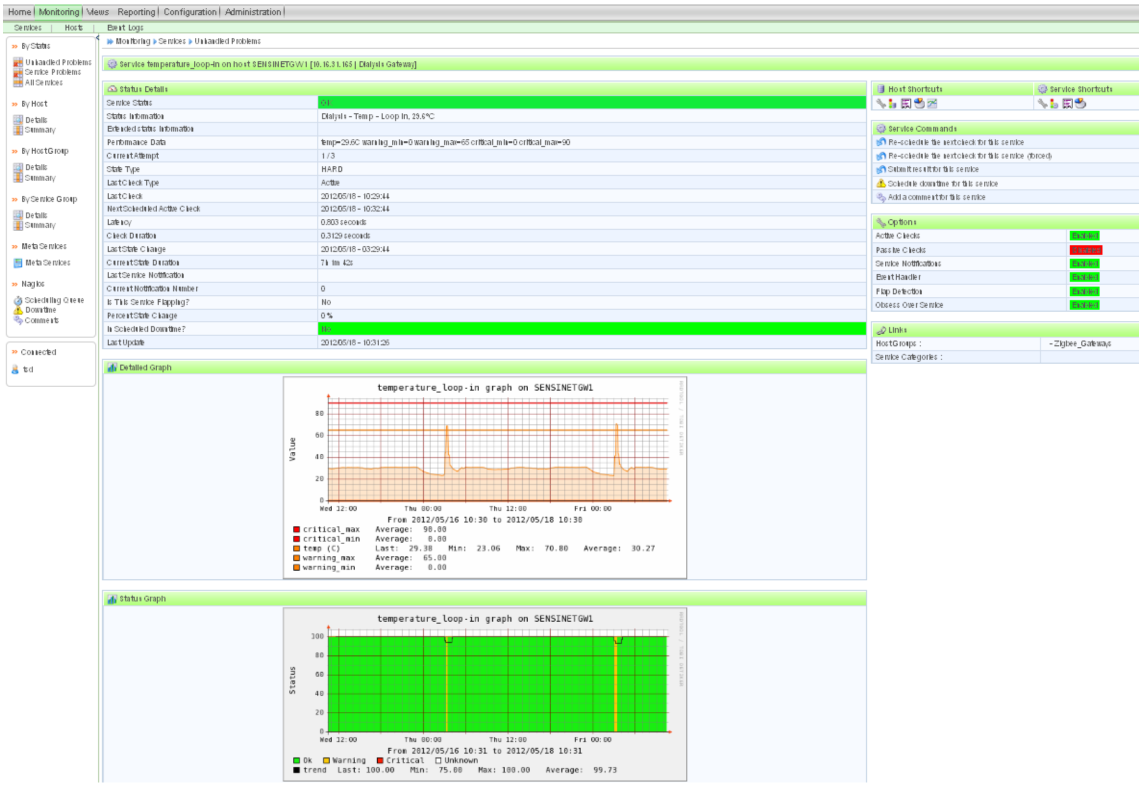


Figure 31 - Example Centreon Icon Browser Window

Within the window, the user can also view:

- Service Status
- Status Information
- Performance Data
- Current Attempt
- State Type
- Last Check Type
- Last Check
- Next Scheduled Active Check
- Latency
- Check Duration
- Last State Change
- Current State Change
- Last Service Notification

- Current Notification Number
- In Schedule Downtime
- Last Update

Graphs will also appear below the data, which can be viewed in more detail by clicking on the particular graph.

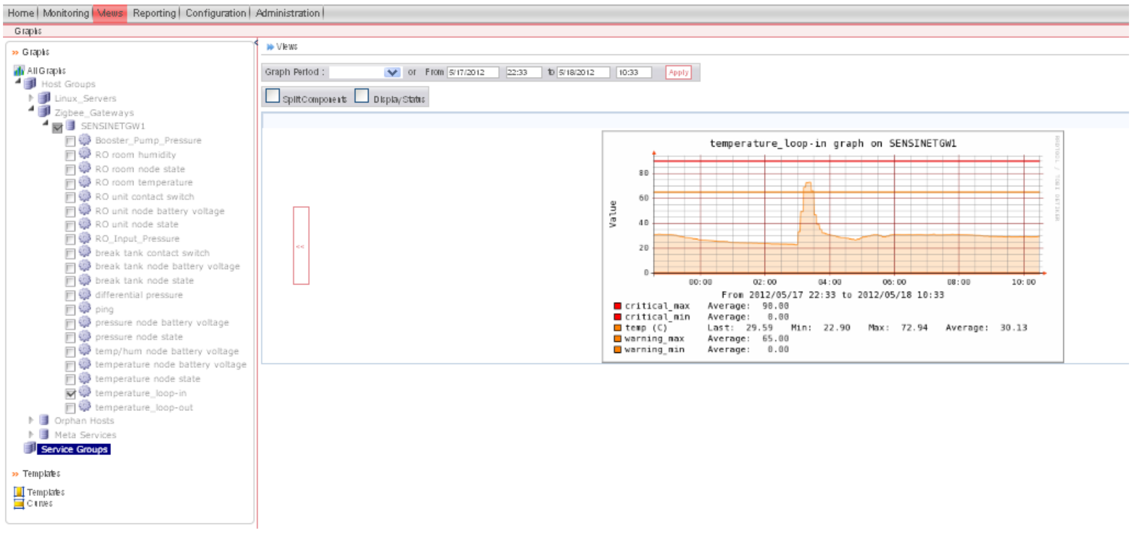


Figure 32 - Example Detailed Graph Analysis

Here, the user can choose the graph period (i.e. last 24 hours, 7 days, 31 days etc.) or choose the exact dates that would like to be viewed. By clicking again on the graph, four graphs appear showing the daily, weekly, monthly and yearly data. See Figure 33below for the four graph example:

Figure 33 - Centreon Web Browser with Daily, Weekly, Monthly and Yearly Data Graphs

Configuring Alarm Limits and Email Addresses

The Centreon plug-in Perl code was designed so that the user can configure the alarm limits by adjusting the values for Warning Minimum, Critical Minimum, Warning Maximum and Critical Maximum. This way, the alarm limits can be set very specific for all nodes.

Email addresses have also been configured to alert the relevant people of alarm limits relating to the data they would like monitored. The email sent out from Centreon allows the user to know the:

- Time and Date
- Node Type
- Node Value
- Alarm limit

- Performance Data (all configured limits for that node)

An example e-mail alarm message is below:

***** Centreon Notification *****

Notification Type: PROBLEM

Service: RO_Input_Pressure

Host: Dialysis Gateway

Address: 10.16.31.165

State: WARNING

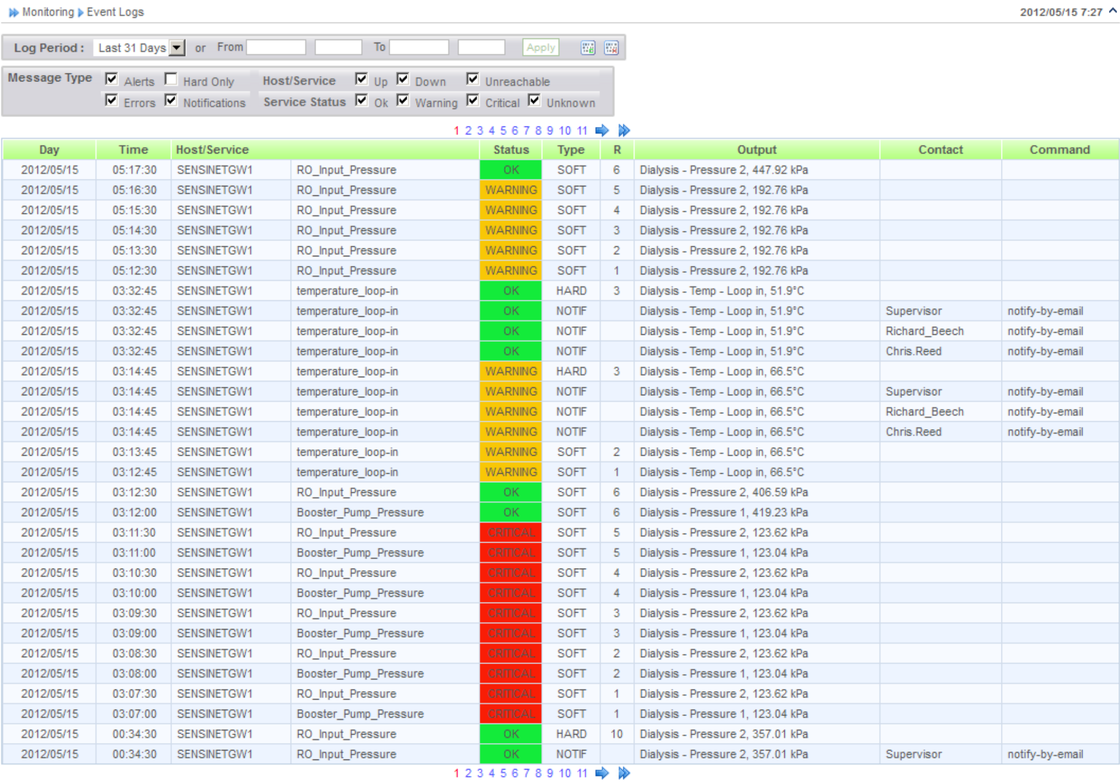
Date/Time: 17-05-2012 Additional Info: Dialysis – Pressure 2, 194.69 kPa

Performance Data: pressure=195kPa warning_min=200 warning_max=600

critical_min=150 critical_max=700

From this data, the user knows exactly what the problem is at first glance and allows faster resolution. Because of the sterilization process done every morning in the Pre-Treatment Plant, the limits of Temperature Loop-in were configured so that an email alarm would be sent every morning when the temperature reaches above 65°C, so the TSD staff would know that sterilization has been completed each night. If sterilization did not occur then there is the possibility that the RO machine might malfunction which could compromise patient health. The Temperature Loop-out limits were configured above 100°C (much higher than the maximum sterilization temperature) so that no email alarm would be sent. This was to reduce the amount of email traffic received by users.

If the user would like to see all events in a Tabular form, Centreon also has this capability:



Monitoring ▸ Event Logs   2012/05/15 7:27

Log Period : Last 31 Days or From To Apply

Message Type ☑ Alerts ☐ Hard Only ☑ Errors ☑ Notifications
Host/Service ☑ Up ☑ Down ☑ Unreachable
Service Status ☑ Ok ☑ Warning ☑ Critical ☑ Unknown

1 2 3 4 5 6 7 8 9 10 11

Day	Time	Host/Service		Status	Type	R	Output	Contact	Command
2012/05/15	05:17:30	SENSINETGW1	RO_Input_Pressure	OK	SOFT	6	Dialysis - Pressure 2, 447.92 kPa		
2012/05/15	05:16:30	SENSINETGW1	RO_Input_Pressure	WARNING	SOFT	5	Dialysis - Pressure 2, 192.76 kPa		
2012/05/15	05:15:30	SENSINETGW1	RO_Input_Pressure	WARNING	SOFT	4	Dialysis - Pressure 2, 192.76 kPa		
2012/05/15	05:14:30	SENSINETGW1	RO_Input_Pressure	WARNING	SOFT	3	Dialysis - Pressure 2, 192.76 kPa		
2012/05/15	05:13:30	SENSINETGW1	RO_Input_Pressure	WARNING	SOFT	2	Dialysis - Pressure 2, 192.76 kPa		
2012/05/15	05:12:30	SENSINETGW1	RO_Input_Pressure	WARNING	SOFT	1	Dialysis - Pressure 2, 192.76 kPa		
2012/05/15	03:32:45	SENSINETGW1	temperature_loop-in	OK	HARD	3	Dialysis - Temp - Loop in, 51.9°C		
2012/05/15	03:32:45	SENSINETGW1	temperature_loop-in	OK	NOTIF		Dialysis - Temp - Loop in, 51.9°C	Supervisor	notify-by-email
2012/05/15	03:32:45	SENSINETGW1	temperature_loop-in	OK	NOTIF		Dialysis - Temp - Loop in, 51.9°C	Richard_Beech	notify-by-email
2012/05/15	03:32:45	SENSINETGW1	temperature_loop-in	OK	NOTIF		Dialysis - Temp - Loop in, 51.9°C	Chris.Reed	notify-by-email
2012/05/15	03:14:45	SENSINETGW1	temperature_loop-in	WARNING	HARD	3	Dialysis - Temp - Loop in, 66.5°C		
2012/05/15	03:14:45	SENSINETGW1	temperature_loop-in	WARNING	NOTIF		Dialysis - Temp - Loop in, 66.5°C	Supervisor	notify-by-email
2012/05/15	03:14:45	SENSINETGW1	temperature_loop-in	WARNING	NOTIF		Dialysis - Temp - Loop in, 66.5°C	Richard_Beech	notify-by-email
2012/05/15	03:14:45	SENSINETGW1	temperature_loop-in	WARNING	NOTIF		Dialysis - Temp - Loop in, 66.5°C	Chris.Reed	notify-by-email
2012/05/15	03:13:45	SENSINETGW1	temperature_loop-in	WARNING	SOFT	2	Dialysis - Temp - Loop in, 66.5°C		
2012/05/15	03:12:45	SENSINETGW1	temperature_loop-in	WARNING	SOFT	1	Dialysis - Temp - Loop in, 66.5°C		
2012/05/15	03:12:30	SENSINETGW1	RO_Input_Pressure	OK	SOFT	6	Dialysis - Pressure 2, 406.59 kPa		
2012/05/15	03:12:00	SENSINETGW1	Booster_Pump_Pressure	OK	SOFT	6	Dialysis - Pressure 1, 419.23 kPa		
2012/05/15	03:11:30	SENSINETGW1	RO_Input_Pressure	CRITICAL	SOFT	5	Dialysis - Pressure 2, 123.62 kPa		
2012/05/15	03:11:00	SENSINETGW1	Booster_Pump_Pressure	CRITICAL	SOFT	5	Dialysis - Pressure 1, 123.04 kPa		
2012/05/15	03:10:30	SENSINETGW1	RO_Input_Pressure	CRITICAL	SOFT	4	Dialysis - Pressure 2, 123.62 kPa		
2012/05/15	03:10:00	SENSINETGW1	Booster_Pump_Pressure	CRITICAL	SOFT	4	Dialysis - Pressure 1, 123.04 kPa		
2012/05/15	03:09:30	SENSINETGW1	RO_Input_Pressure	CRITICAL	SOFT	3	Dialysis - Pressure 2, 123.62 kPa		
2012/05/15	03:09:00	SENSINETGW1	Booster_Pump_Pressure	CRITICAL	SOFT	3	Dialysis - Pressure 1, 123.04 kPa		
2012/05/15	03:08:30	SENSINETGW1	RO_Input_Pressure	CRITICAL	SOFT	2	Dialysis - Pressure 2, 123.62 kPa		
2012/05/15	03:08:00	SENSINETGW1	Booster_Pump_Pressure	CRITICAL	SOFT	2	Dialysis - Pressure 1, 123.04 kPa		
2012/05/15	03:07:30	SENSINETGW1	RO_Input_Pressure	CRITICAL	SOFT	1	Dialysis - Pressure 2, 123.62 kPa		
2012/05/15	03:07:00	SENSINETGW1	Booster_Pump_Pressure	CRITICAL	SOFT	1	Dialysis - Pressure 1, 123.04 kPa		
2012/05/15	00:34:30	SENSINETGW1	RO_Input_Pressure	OK	HARD	10	Dialysis - Pressure 2, 357.01 kPa		
2012/05/15	00:34:30	SENSINETGW1	RO_Input_Pressure	OK	NOTIF		Dialysis - Pressure 2, 357.01 kPa	Supervisor	notify-by-email

1 2 3 4 5 6 7 8 9 10 11

Figure 34 - Centreon Event Log Table

Problems Encountered

When the project was first being planned, it was understood that Wireless Sensors had configured SNMP through their gateways Web Server. Once it was time to configure the FAN Server, we tried to communicate to the gateway through SNMP communication but came across many problems. No communication could be made. After trying to contact Wireless Sensors about this problem they offered a few solutions that may have helped. After trying all their suggested solutions, there was still no SNMP communication, so other options were looked into.

The gateway and Web Server had already been configured for ODBC, so this option was looked into further. Other FAN users had used ODBC in the past and found it successful, but there were no general plug-ins that could have been used for this project. This meant a Perl script needed to be created to pull data from the Web Servers tables. Only one Technical Officer within TSD had ever programmed in Perl, so research was done and examples were found to try and create the unique Perl script this project needed. This problem, as well as trying to solve the SNMP communication problem, set the project back approximately five weeks, which caused a domino effect leading to not enough time being left to fully complete the TSSU and Gastroenterology installations.

Some advantages of ODBC over SNMP include:

- Able to get virtual port information as well as raw data.
- The data can be formatted within the plug-in code which is sent to Centreon via ODBC. This was beneficial for the temperature data, because the plug-in code could limit the decimal places to 2, whereas Centreon does not have this capability if data was sent directly via SNMP.
- Easier to add new channels into the plug-in code.

Some limitations of the FAN Software include:

- Cannot configure emails to alert users if the Loop-in Temperature does not go over the sterilization unit temperature.
- Cannot remove extra information that is not required on the Centreon web page.
- There are limited options for the graph formats, user cannot change colours and cannot overlay values with alarms.
- Cannot delay the response when an alarm is triggered so the user can ignore short spikes. It would be more convenient to only send genuine email alarms to let the user know when the data goes low/high for ‘x’ minutes.

Chapter 6: Theatre Sterile Supply Unit (TSSU) and Gastroenterology Install

System Planning

System planning for TSSU and Gastroenterology was very similar to the Pre-Treatment Plant. A HMI layout and Wiring Diagram were created ready for the TSSU and Gastroenterology installations, and because this is a repeat project of Haemodialysis, it was known what to expect when it came to ordering sensors from Wireless Sensors and how long they would take to arrive. A theoretical design plan of where all sensors, ethernet ports and GPOs are going to be positioned was also created. This would enable a smoother handover when this project ends and installation takes place.

See Appendix D for the TSSU Wiring Diagram.

Purchasing and Fabrication

The hardware that will be bought from Wireless Sensors for TSSU includes:

- 1 x Gateway with mounting bracket
- 2 x RTD Temperature sensors
- 2 x 4-20mA Current sensors

The hardware that will be bought for Gastroenterology includes:

- 1 x Gateway with mounting bracket
- 3 x RTD Temperature sensors
- 3 x 4-20mA Current sensors

Similar PVC backing boards and power supply boxes will be created by the Instruments Workshop within TSD again and installed in both TSSU and Gastroenterology, both facilities will also have a local PC tablet installed for staff to be able to monitor pressure and temperature readings locally.

Installation

Installation of the Wireless Sensors hardware will be done at a later stage, but Facilities Management has already been contacted, and red essential GPOs and double ethernet ports have been installed. Installation will be similar to Haemodialysis where Facilities Management will only need to mount the PVC backing board and conduit onto the wall.

Commissioning

Commissioning of both these systems will be exactly the same as Haemodialysis, Centreon Plug-in Perl Code will be used again, rather than using the now configured SNMP communication (configured after this project was completed) through the Wireless Sensors Gateway. The NagVis templates have already been uploaded ready for the Centreon Plug-in. Changes to the alarm limits will need to be made specific to TSSU and Gastroenterology such as pressure and temperature limits, but these will be set by the Technical Officer in charge of those departments.

See Appendix F for the TSSU and Gastroenterology NagVis templates.

RPH Documentation

There will not be much documentation for the TSSU and Gastroenterology installations, because they are replicas of the Pre-Treatment Plant installation, except for a few minor changes. For example, specific IP addresses, new login details and new advised limits.

Chapter 7: Concluding Remarks

Project Conclusions

Through this thesis, a solution to the monitoring of temperatures, pressures and contact switches has been found. Two wireless ZigBee solutions were tested and compared against each other, with the preferred solution being Wireless Sensors SensiNet system. Their system was able to satisfy many more requirements than the other Fourtec DataNet system.

All hardware was bought or calibrated ready to install, and with the help of facilities management, installation took place over three days. Wireless Sensors Web Server was configured for all nodes, required alarm limits and email notifications for all relevant people. Commissioning involved writing up a Service Manual detailing all setup steps and default logins.

A chlorine analyser was researched to try and find a fully automated solution for the Haemodialysis nurses. However it was found that the option would not be cost effective and the nurses had shown a strong dislike to the idea. The chlorine analyser however could still be an option for future Haemodialysis Pre-Treatment Plants in other hospitals.

Once the SensiNet Web Server was configured and commissioning was complete, researching NagVis, Nagios and Centreon began. A Perl Script was developed and tested to setup communication between the gateway and FAN. From here, a Human Machine Interface (HMI) was designed to represent Haemodialysis Pre-Treatment Plant layout, which any remote user could use to monitor through a standard web browser all sensor values and status information.

From here the project could move onto preparing similar monitoring systems in TSSU and Gastroenterology. Wiring diagrams, system plans and NagVis templates were designed for the future installations, the power and communications infrastructure was put in place in TSSU.

Through all stages of this project a variety of documents were created for use as manuals for future monitoring systems. These documents summarize the setup details, commissioning, and configuration of the installation, web server and FAN server. A service manual was also created for the setup, installation, calibration and maintenance of the system.

Evaluation of the project shows that the project achieved almost all the goals originally set out with the exception of completing the TSSU and Gastroenterology installations, as well as

starting the PathWest Laboratories installation, which will be now completed by the Clinical Engineer and TSD team.

Proposed Future Works

This project will be used again in the proposed Haemodialysis Ward at Armadale Hospital, also within Laboratories at Royal Perth Hospital. The Laboratory installation will be a much larger system, with thousands of sensors, monitoring for example Cold Room and Clean Room temperatures, Cryo Tank temperatures and pressures, and contact closures for multiple water tanks etc. And hence will require a full professional SCADA system. Once the project has been implemented within the Laboratories of PathWest, it has been proposed to be used within other hospitals of Western Australian Health, in an attempt to streamline all monitoring systems, with a cost effective and user friendly option.

Although the Nagios Software used for this Project was a sufficient solution for monitoring sensors, there are two new possible software solutions that have been released that could provide a better monitoring system to work in parallel with Centreon and NagVis. The first of these solutions is Centreon Broker which presents a new way to store Nagios events in a database. Centreon Broker offers the user the ability to setup an auxiliary database which will only monitor a part of the IT infrastructure. It relies on the standard TLS (Transport Layer Security) protocol that supplies an encryption on all data flows over the network used. All incoming data is therefore protected from any person or third party programs. Centreon Broker relies on prepared statements which allow two main kinds of optimizations. First, when similar queries are performed multiple times, the analysis of the database only occurs once. Second, data is sent using binary protocol instead of a plain-text one, which reduces network management and the size of data to process.

The second of these new solutions is Shinken which has the same capabilities of Nagios with more advanced built-in facilities, e.g. load balanced and high availability monitoring. Shinken is a Nagios like tool, redesigned and rewritten from scratch to complete more requirements of system monitoring, but still allowing the compatibility to the Nagios ecosystem. The Shinken architecture is its major strength; it is a private cloud based monitoring system. It allows users to manage large configurations with lots of dependencies with minimal issues. It can monitor more than 10,000 hosts with a single server.

Reusability of the Project

The Haemodialysis Pre-Treatment Plant Monitoring System project has formed the basis of a simple, cost effective and reusable solution for remote monitoring. It is easy to see from the

Proposed Future Works above, that this project has great potential to influence not only other installations within RPH, but also other Western Australian Hospitals. Consistent commissioning and good documentation has led to this project being easily reused with most of the problems being smoothed out during the completion of this project.

TSD Staff Training for Future Usage

At the end of this project, Training was arranged for the TSD Staff that would be implementing this system. The training allowed them to learn how to use the designed FAN Server, showing them how to configure new alarm limits, change or upload a new background screen, test changes to the Perl script and to add or change email notifications. A service manual was also written up in case there were any future questions, outlining how to configure all settings in Centreon, any default logins and the locations of all finished NagVis templates. With training for staff completed, the future extensions of this project will now be much easier.

Final Project Gantt Chart

The final Gantt Chart (Figure 35 below) displays the actual timeline of this Project, and explains the time taken to fulfil the minor steps of each Stage. The two largest stages were the Haemodialysis Installation and FAN (NagVis) Server. These two stages had a lot more work and research required to understand the requirements but was also delayed because of the time taken for the final hardware to arrive to finalise installation. Stage one was completed quickly because all hardware and software had already been sent and was ready for testing when the Project began. Documentation was recorded throughout the entire testing stage to try and reduce the amount at the end.

Stage three also had a large delay which can be seen in the Gantt Chart, this is because of the time taken waiting for Wireless Sensors to configure SNMP on the gateway that was sent to RPH.

Stage four took a little bit longer than expected because it was done in parallel with stage three, but it will simplify the TSSU and Gastroenterology installations when they are ready to commence.

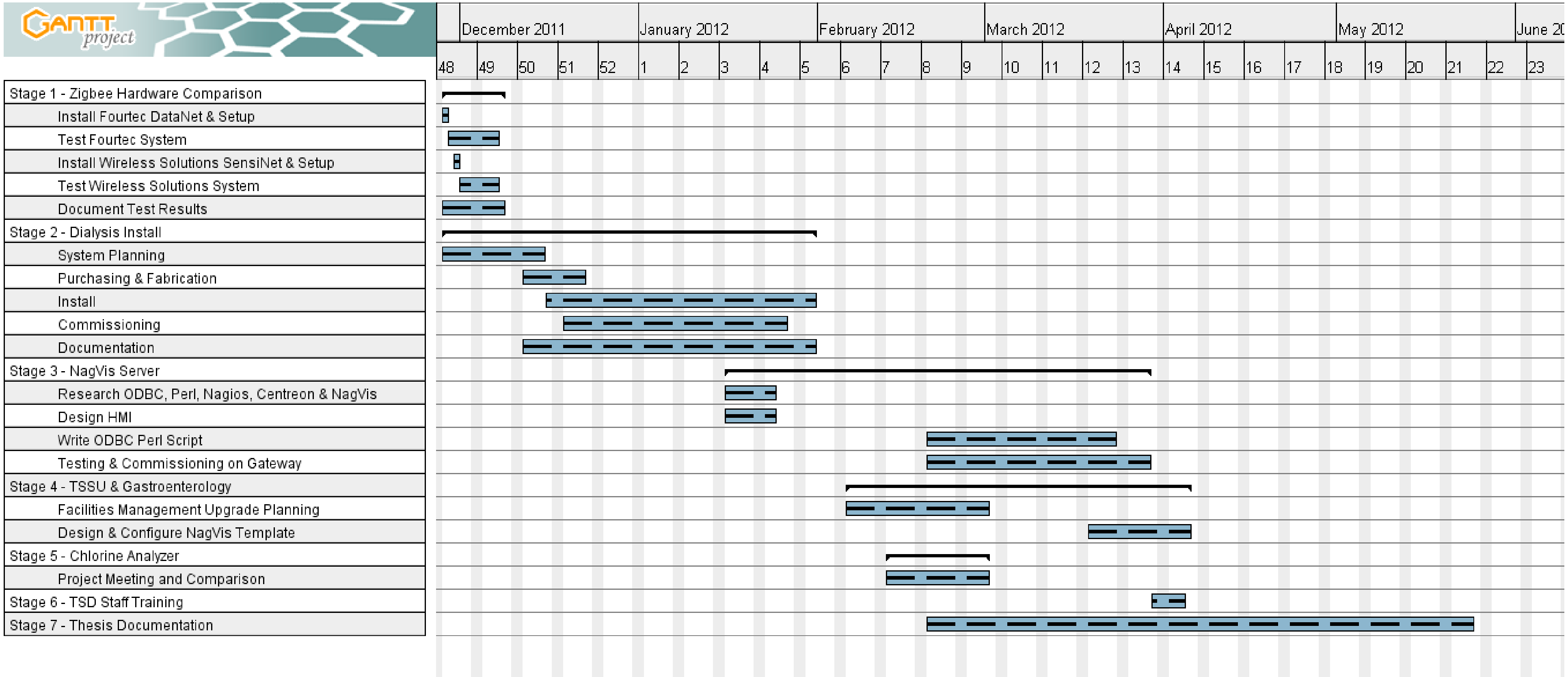


Figure 35 - Final Project Gantt Chart

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Appendices

Appendix A: Pre-Treatment Plant Overview

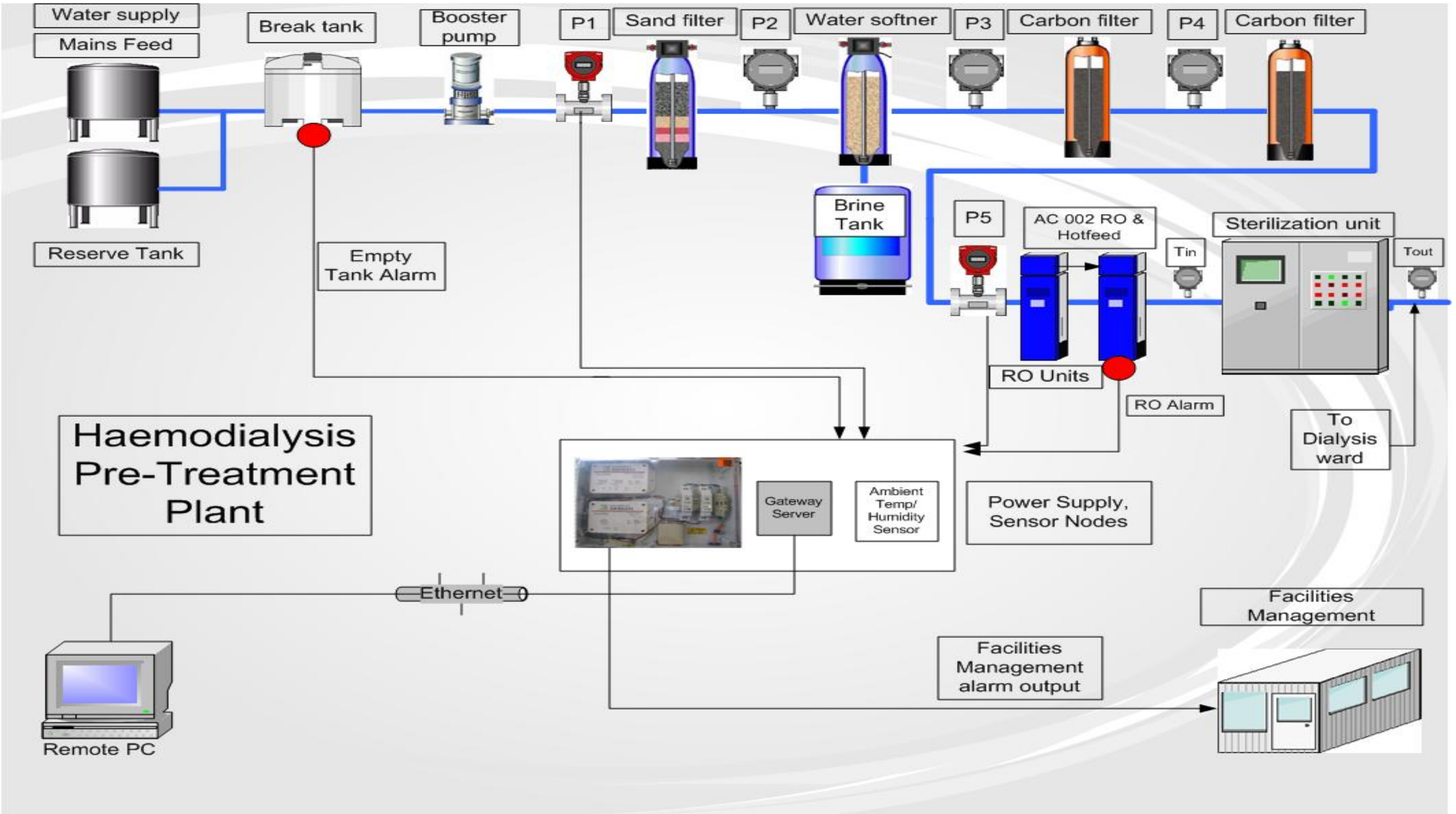

Figure 36 - Haemodialysis Pre-Treatment Plant System Overview (RPH, 2011)

Appendix B: Haemodialysis Installations Photographs

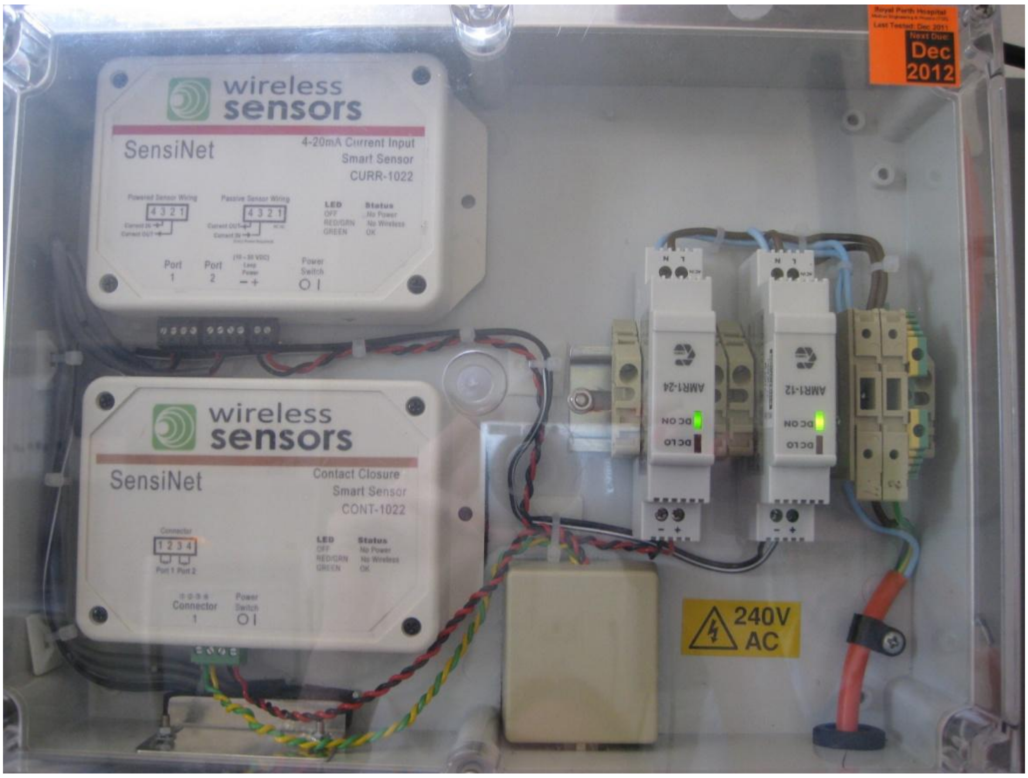

Figure 37 - Power Supply Box

Figure 38 - Final mounted system on PVC backing board

Figure 39 - RTD Temperature Sensor monitoring Incoming and Outgoing Temperatures

Figure 40 - Pressure Transducer 2 in situ

Figure 41 - Break Water Tank

Figure 42 - Break Water Tank Contact Closure Sensor

Appendix C: Haemodialysis Wiring Diagrams

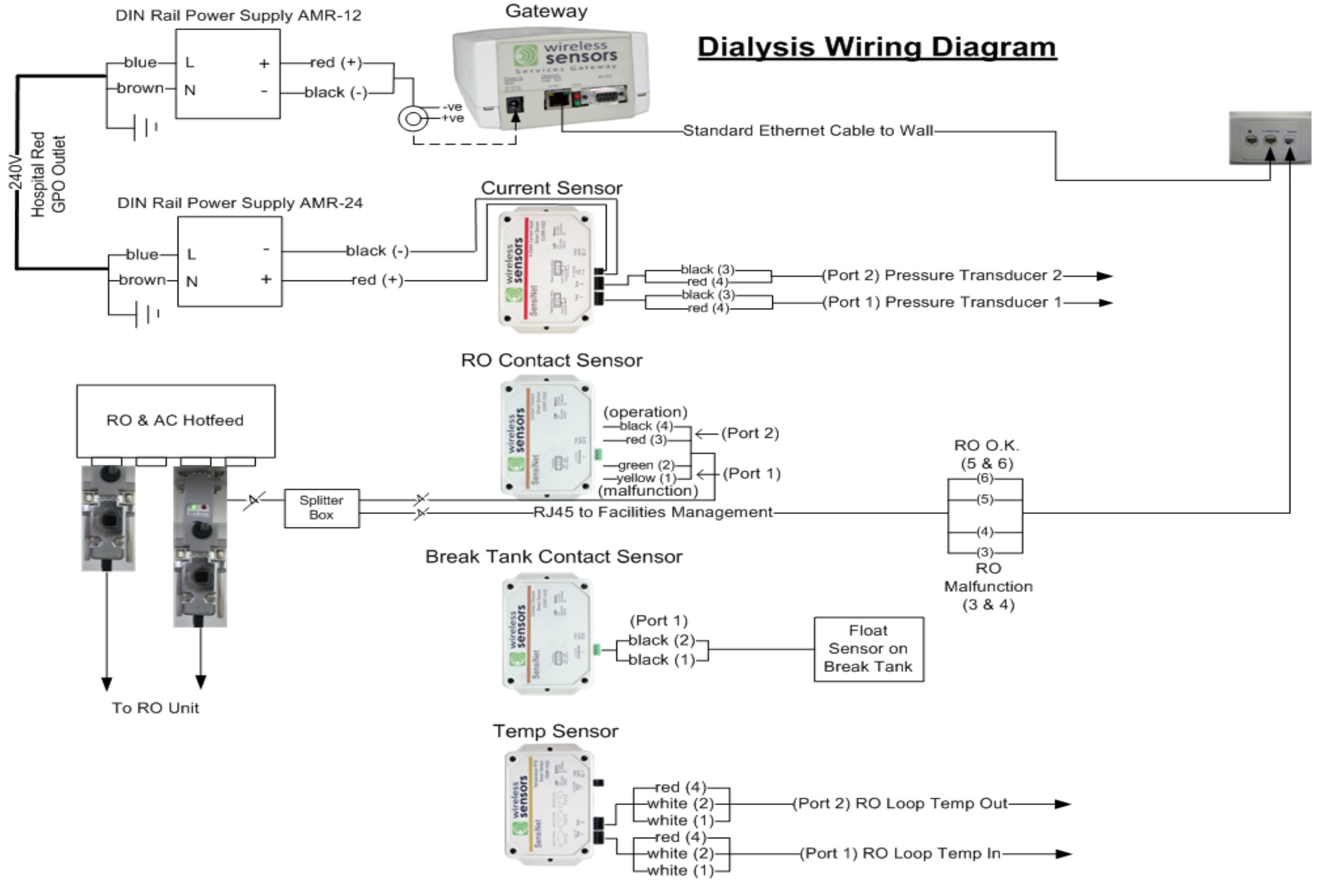

Figure 43 - Haemodialysis Wiring Diagram

Appendix D: TSSU Wiring Diagrams

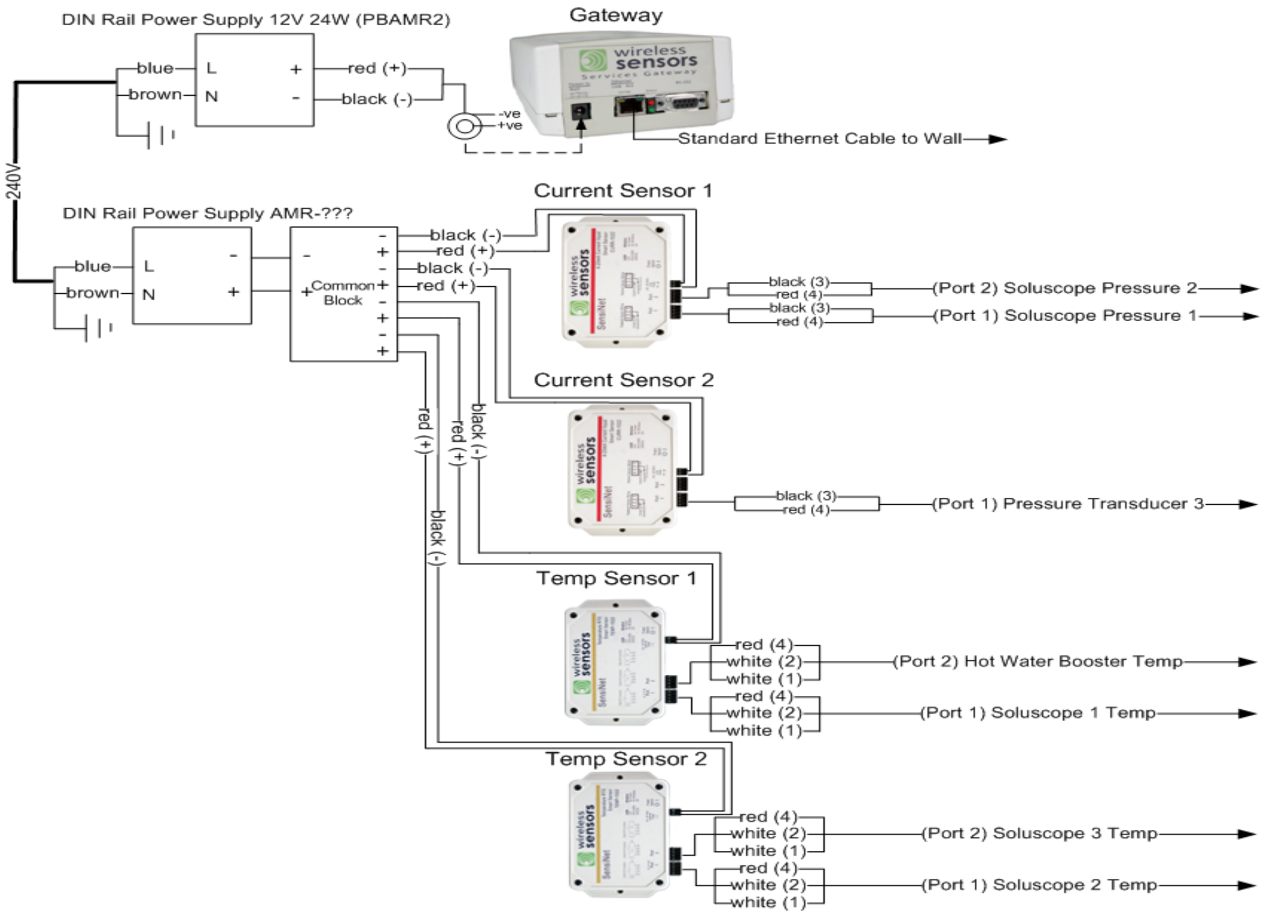

Figure 44 - TSSU Wiring Diagram

Appendix E: Centreon Plug-in Perl Code

```
#! /usr/bin/perl

####################################################################

#       Nagios Plugin to retrieve data from Sensinet gateway            #

#       Uses Postgresql database connection                             #

#                                                                       #

#       Authors: Mike Hill, Jarrad Coyle, Chantal Oliver                #

#                                                                       #

####################################################################


use utf8;

use DBI;


#Shift command line arguments into variables (done in order given)

my $host_address = shift;

my $node_location_name = shift;

my $value_type = shift;


# Return codes: OK=0, Warning=1, Critical=2, Unknown=3

my $warning_min = shift;

my $warning_max = shift;

my $critical_min = shift;

my $critical_max = shift;

my $return_code = 0;

my $sth;


#Connect to the database
```

```
my $dbh = DBI -> connect
("DBI:Pg:dbname=gwdb;host=$host_address;port=5432","gb1","viper") or die ("Unable to
connect to database!\n");


#Prepare the SQL query

if ($value_type eq "voltage")

        {$sth = $dbh-> prepare('SELECT node_battery_voltage.voltage FROM
node_battery_voltage, data_current WHERE
node_battery_voltage.node_id=data_current.node_id AND data_current.location_name = ?')
or die "Couldn't prepare statement: ".$dbh->errstr;}

        else {$sth = $dbh-> prepare('SELECT data_current.data_value FROM
public.data_current data_current WHERE data_current.location_name = ?') or die "Couldn't
prepare statement: ".$dbh->errstr;}


#Create data aray for the results of the query to go into

my @data;


#Execute the query passing the location name to the previously prepared SQL statement

$sth->execute($node_location_name);


#Fetch the results of the query into the data array and print results

@data = $sth->fetchrow_array();

$data[0] =~ s/^\s+//;

if (($value_type eq "temp") || ($value_type eq "humidity"))

        {$data[0]=$data[0]/100;}


#Check if data is within limits

if ($data[0] < $warning_min)

        {$return_code = 1;} elsif ($data[0] >= $warning_max)

        {$return_code = 1;}

if ($data[0] < $critical_min)
```

```
            {$return_code = 2;} elsif ($data[0] >= $critical_max)
            {$return_code = 2;}


#Format unit output for value type
if ($value_type eq "temp")
            {print ("$node_location_name, ");
            printf ("%.1f\xc2\xb0C",$data[0]);} elsif ($value_type eq "pressure")
                        {print ("$node_location_name, ");
                        print ("$data[0] kPa");} elsif ($value_type eq "humidity")
                        {print ("$node_location_name, ");
                        printf ("%.2f%",$data[0]);} elsif ($value_type eq "voltage")
                        {print ("$node_location_name. Battery Voltage - ");
                        print ("$data[0] Volts");} elsif ($value_type eq "contact")
                        {print ("$node_location_name. Contact - ");
                        print ("$data[0]");}
print ("\n");
if ($value_type eq "temp")
{printf ("|temp=%.1fC warning_min=%d warning_max=%d critical_min=%d
critical_max=%d",$data[0],$warning_min,$warning_max,$critical_min,$critical_max);}
if ($value_type eq "pressure")
{printf ("|pressure=%.0fkPa warning_min=%d warning_max=%d critical_min=%d
critical_max=%d",$data[0],$warning_min,$warning_max,$critical_min,$critical_max);   }
if ($value_type eq "humidity")
{printf ("|humidity=%.0f% warning_min=%d warning_max=%d critical_min=%d
critical_max=%d",$data[0],$warning_min,$warning_max,$critical_min,$critical_max);}
if ($value_type eq "voltage")
{printf ("|voltage=%dV warning_min=%d warning_max=%d critical_min=%d
critical_max=%d",$data[0],$warning_min,$warning_max,$critical_min,$critical_max);   }
if ($value_type eq "contact")
```

```
{printf ("|Contact=%d warning_min=%d warning_max=%d critical_min=%d critical_max=%d",$data[0],$warning_min,$warning_max,$critical_min,$critical_max);}

$sth->finish;


#Disconnect from the database

$dbh->disconnect;


#Exit with return code for centreon to act on

exit ($return_code);
```

Appendix F: NagVis Templates

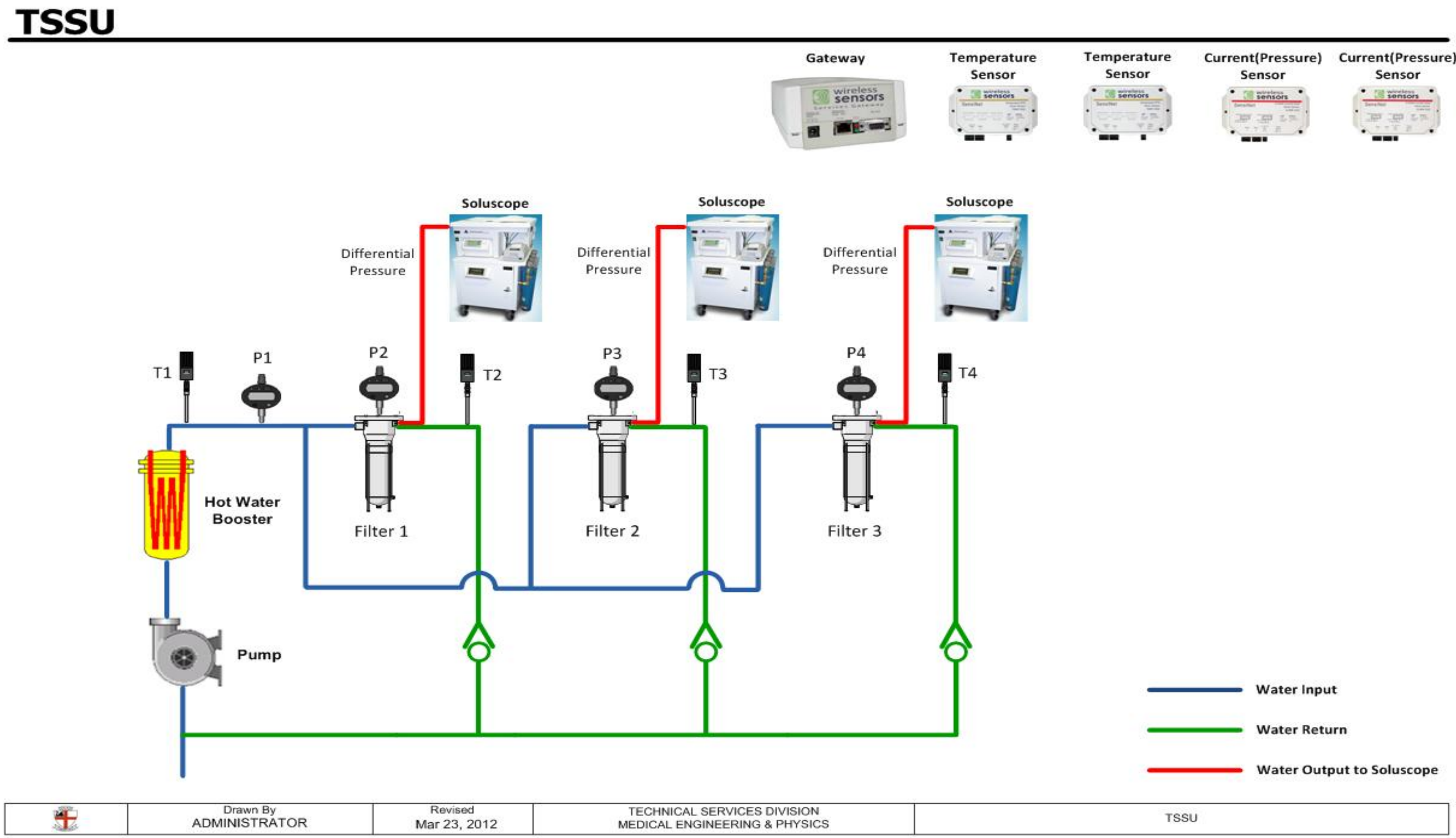

Figure 45 - TSSU NagVis Template

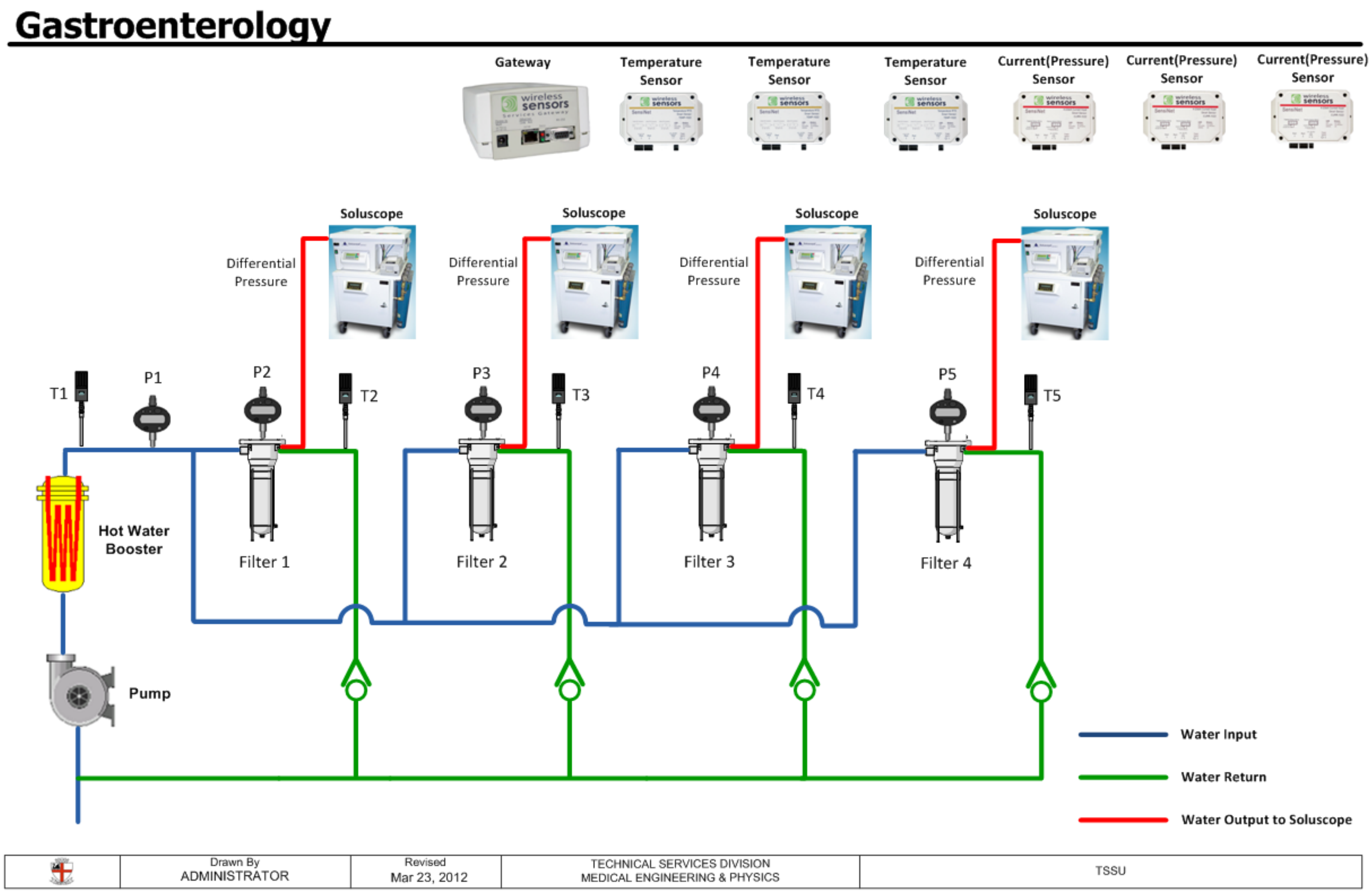

Figure 46 - Gastroenterology NagVis Template

Appendix G: Power Supply Box (Controller Unit) Billing of Materials

Manufacturer/ Supplier Part	TITLE or DESCRIPTION	U.O.M	QTY	Cost Each	Cost Total	Item No.
ROSE RS 138-206	ENCLOSURE CLEAR LID 300mm (L) X 230mm (W) X 85mm (H) POLYCARBONATE IP65	EA	1	$160	$160.00	1
WEIDMULLER FAR 113-1792	DIN TERMINAL BLOCK, EARTH H=47mm, W=60mm	EA	1	13.15	13.15	2
WEIDMULLER FAR 113-1753	DIN RAIL MOUNT FUSE FOLDER SAK SERIES 5 x 20mm 6.3A 500V **<<FOR ACTIVE and NEUTRAL>>**	EA	2	$21.01	$42.02	3
ALTRONICS S 5724	M 205 (20 x 5mm) 1A QUICK BLOW (RS 416-297 LITTLEFUSE $0.10 ea)	EA	2	$0.35	$0.70	4
WEIDMULLER FAR 117-117	DIN TERMINAL END SECTION AP SERIES 45.5mm(H) **<<AFTER FUSE HOLDERS>>**	EA	1	$3.87	$3.87	5
WAGO RS 425-314	DIN 35 END STOP 6mm WIDTH (Alternate WAGO FAR 401-6117 $0.95 ea)	EA	4	$1.71	$6.84	6

POWERBOX PBAMR1-12	AC/DC POWER SUPPLY DIN MOUNTABLE 90-264VAC 47-63 Hz 10W 12VDC 830mA TOL: ±1% EFF: 78% 18mm(W) x 50mm (H) x 91mm (L)	EA	1	$45.00	$45.00	7
POWERBOX PBAMR1-24	AC/DC POWER SUPPLY DIN MOUNTABLE 90-264VAC 47-63 Hz 10W 24VDC 420mA TOL: ±1% EFF: 80% 18mm(W) x 50mm (H) x 91mm (L)	EA	1	$45.00	$45.00	8
WEILAND ELECTRIC WS 055-3542	STANDARD TOP-HAT DIN RAIL 0.5m(L)x35mm(W)x7.5mm(H)	EA	1	$10.20	$10.20	9
UNBRANDED 536-805	PVC BASED FORM STRIP 20m(L)x12mm(W)x4.5mm(H) **<<CUT TO LENGTH & PLACE BEHIND SENSINET NODES>>**	EA	1	$22.20	$22.20	10
ALTRONICS H4312	CABLE GLAND IP68 4-8mm EG9/PG9 Black	EA	1	$1.00	$1.00	11
JAYCAR YT6064	RJ45 KEYSTONE SIDE ENTRY BOX SURFACE MOUNT CAT 5E SOCKET 8P/8C	EA	1	$6.50	$6.50	12

WIRELESS SENSORS CURR-1022	SENSINET DUAL PORT CURRENT INPUT 4-20mA IEEE 802.15.4 2.4GHz DFSS **(PRICE IN US DOLLARS)**	EA	1	$300.00	$300.00	13
WIRELESS SENSORS CONT-1022	SENSINET DUAL PORT CONTACT CLOSURE IEEE 802.15.4 2.4GHz DFSS **(PRICE IN US DOLLARS)**	EA	1	$300.00	$300.00	14
RS 356-549	CABLE WIRE SINGLE CORE PVC SHEATH 3Amps/1000V 16/0.2mm YELLOW **<<CUT TO LENGTH AND TWIST>>**	METRE	0.1	$0.33	$0.33	15
RS 356-476	CABLE WIRE SINGLE CORE PVC SHEATH 3Amps/1000V 16/0.2mm GREEN **<<CUT TO LENGTH AND TWIST>>**	METRE	0.1	$0.33	$0.33	16
RS 356-448	CABLE WIRE SINGLE CORE PVC SHEATH 3Amps/1000V 16/0.2mm BLACK **<<CUT TO LENGTH AND TWIST>>**	METRE	0.2	$0.33	$0.07	17
RS 356-527	CABLE WIRE SINGLE CORE PVC SHEATH 3Amps/1000V 16/0.2mm RED **<<CUT TO LENGTH AND TWIST>>**	METRE	0.2	$0.33	$0.07	18

KEY TUBING H3P-IEC3M	MAINS IEC POWER CORD 10A 250Vac 0.75mm^2 TO 1.0mm^2 **<<CUT OFF PLUG AND CONNECT SIDE ENTRY PLUG>>**	EA	1	\$7.30	\$7.30	19
RS 472-6403	P-CLIP NYLON 6.4-9.5mm WHITE (1 BAG OF 25 \$4.11)	EA	1	\$0.16	\$0.16	20
RS 423-9533	VELCRO TICK ON HEAVY DUTY TAPE BLACK 50mm WIDTH (\$80.50 for 5M ROLL)	EA	0.2m	\$5.00	\$5.00	21
				TOTAL	**\$968.94**	

Table 6 - Controller Unit BOM

Appendix H: System Assembly Billing of Materials

Manufacturer/ Supplier Part	TITLE or DESCRIPTION	U.O.M	QTY	Cost Each	Cost Total	Item No.
TSD MECHANICAL	PVC BACK BOARD 1225mm (L) x 300mm (H) x 6mm(W) **<<FACILITIES MANAGEMENT MOUNT ONTO WALL>>**	EA	1	$0	$0.00	1
ENGINEERING FACILITIES	CONDUIT SQUARE WHITE 25mm (W) x 16mm (H) **<<CUT TO SIZE>>**	EA	4m	$0	$0.00	2
MEASUREMENT SPECIALTIES MSP 300 TC Direct 716215	PRESSURE TRANSDUCER 100 psi 4-20mA ¼" NPT – OBSOLETE Replace with: PRESSURE TRANSDUCER 6 bar (600kPa) 4-20mA ¼" BSP ±0.5% 316L Stainless Steel	EA	2	$174.00	$348.00	3
FARNELL 118-2083	BELDON-8205 060U500 CABLE, 8205, 1 PAIR ($364.95 153m REEL)	EA	10m	$24.00	$24.00	4
WIRELESS SENSORS GWAY-1020	SENSINET GATEWAY WITH ETHERNET CONNECTION **(PROCE IN US DOLLARS)**	EA	1	$1495.00	$1495.00	5
WIRELESS SENSORS B1370028	SENSINET GATEWAY BRACKET WALL MOUNT CLIP	EA	1	$0	$0	6

WIRELESS SENSORS TEHU-1121	SENSINET INTEGRATED TEMPERATURE AND HUMIDITY SENSOR IEEE 802.15.4 2.4GHz DFSS **(PRICE IS US DOLLARS)**	EA	1	$300.00	$300.00	7
WIRELESS SENSORS TEMP-1022	SENSINET DUAL PORT RTD MODULE IEEE 802.15.4 2.4GHz DFSS **(PRICE IN US DOLLARS)**	EA	1	$300.00	$300.00	8
WIRELESS SENSORS RTD-1639	SENSINET RTD SENSOR 100Ohm PT 3 WIRE SENSOR **(PRICE IN US DOLLARS)**	EA	2	$75.00	$150.00	9
WIRELESS SENSORS CONT-1022	SENSINET DUAL PORT CONTACT CLOSURE IEEE 802.15.4 2.4GHz DFSS **(PRICE IN US DOLLARS)**	EA	1	$300.00	$300.00	10

BATTERY SPECIALITIES LS-14500	BATTERIES SAFT 3.6V AA 2600mAH LITHIUM-THIONYL CHLORIDE (Li-$SOCl_2$) BOBBIN STYLE Ø14.65mm LENGTH 50.3mm WEIGHT 16.7g **<<REPLACEMENT BATTERY FOR NODES>>** ALTERNATIVES: RS 201-9438 LS-14500 $9.60 ($8.70 / Qty 25) FAR 186-5217 LS14500EX $10.60 ($9.55 / Qty25) SIOMAR STC-AA 2400mAH $12 SIOMAR ER18505 3200mAH $12 WIRELESS SENSORS XL-060F 2400mAH	EA	0	$12.62	$0.00	11
FARNELL 1515108	CAT6 FLAT CABLE UTP WITH RJ45 CONNECTOR 2m	EA	1	$5.87	$5.87	12
INSTRUMENTS WORKSHOP	M4 THREAD INSERTS	EA	8	$0	$0	13
INSTRUMENTS WORKSHOP	M4 SOCKET HEAD ALLEN SCREWS 6mm	EA	6	$0	$0	14
INSTRUMENTS WORKSHOP	TESA DOUBLE SIDED STICKY 4965 (25mm Wide) **<<CUT TO SIZE>>**	EA	50m roll	$0	$0	15

CLIPSAL 418S TR	MAINS 10A 250VAC SIDE ENTRY PLUG 0.75mm^2 TO 1.0mm^2 CABLE CLEAR COVER	EA	1	$5.87	$5.87	16
FARNELL 1515108	CAT6 FLAT CABLE UTP WITH RJ45 CONNECTOR 2m	EA	1	$5.87	$5.87	17
ALTRONICS P7052A	PHONE DOUBLE ADAPTER RJ45 SOCKET x 2, RJ45 PLUG (8P/8C) (JAYCAR YT6082 $11.95)	EA	1	$2.15	$2.15	18
	CONTROLLER UNIT ASSEMBLY (See E11002ax_Controller Unit.bom)	EA	1	$968.94	$968.94	19
				TOTAL	**$3905.70**	

Table 7 - System Assembly BOM